Relative Advantages of Modern Steam and Electric Locomotives

By JOHN E. MUHLFELD

Member

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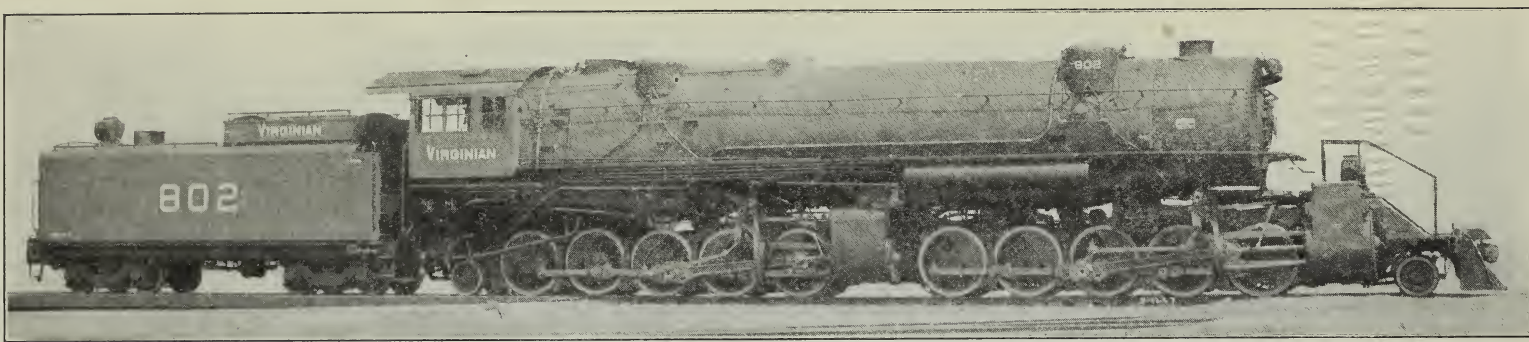
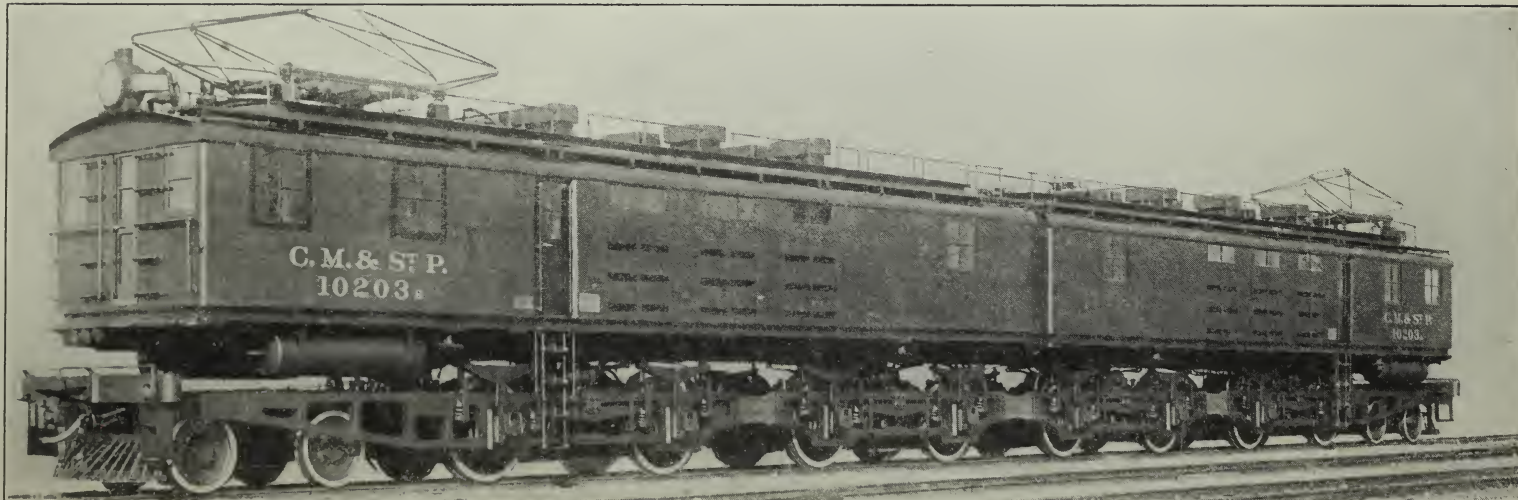


Virginian Articulated Type Steam Locomotive Described on Page 14. Tractive Power, Maximum 176,000 Lbs.—at 15 Miles per Hour 108,000 Lbs.



St. Paul Articulated Type Electric Locomotive Described on Page 14. Tractive Power, Maximum 132,500 Lbs.—at 15 Miles per Hour 71,000 Lbs.

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By John E. Muhlfeld

Vice-President, Railway and Industrial Engineers, Incorporated

PREFACE

Mr. Chairman, Members and Guests:

1. I have the highest regard for my colleague, Mr. Frank J. Sprague, who opened this meeting, not only as a man, but as an electrical engineer who has done things, and I feel that the following extract from his address at the 30th Anniversary of the Electrical Exhibition in Philadelphia in August, 1914, is well worth repeating at this time.

2. "One of the great ambitions of all of us has been to electrify the railroads of the world, especially the trunk line railroads. It has been a common prophecy of electrical engineers that main line railroads would be early electrified, and the steam locomotive thrown into the discard. Hopes have outpaced facts, for when the gilded electric giant—and gilded it must be because of the large amount of capital required—goes into the arena to meet its iron-clad opponent, the modern steam locomotive, on the basis of comparative economy of operation and capacity, it has been a hard row to hoe.

3. In the urban, suburban, and interurban fields, and now also in terminal operation, electricity holds its own, because it deals with classes of traffic often impossible for like operation by steam; but when we get into the trunk line operated field we must then discard a great deal of existing investment, and must incur large investments at a time when money is very difficult to raise."

4. In prefacing my conclusions and the supporting data on "The Relative Advantages of Modern Steam and Electric Locomotives," and in view of the circular announcing this meeting being captioned "Railroad Electrification Night" I wish to refer for the moment to a similar memorial that I presented at a meeting of the New York Railroad Club in Carnegie Hall, on February 16, 1906, on "Large Electric and Steam Locomotives." That paper was based, generally, on the relative performances on The Baltimore and Ohio Railroad of two geared electric locomotives,

each consisting of two units, which operated through seven tunnels over 3.4 miles of line ranging from 0.8 to 1.5% up-grade, with a ruling grade of 7/8 mile of 1.4 and 1.5 percent east-bound through Baltimore City, and of one Mallet type steam locomotive which operated over 16½ miles of line ranging from 0.5 to 1.0 percent up-grade, with a ruling grade of 6½ miles of 1.0 percent east-bound, over the Allegheny Mountains. Both the electric and steam locomotives were of about the same tractive power rating, built and put into helper service at about the same time, and I desire to quote from that paper and to again—14 years later—reiterate as follows:

5. "What the stock owners and heads of railroads generally desire is to originate and move the greatest amount of business possible with the least cost to Capital and Operating Accounts."

6. "The locomotive problem must be attacked from a combined Transportation and Motive Power, and not from an Electrical or Mechanical Engineer's viewpoint. There are sufficient locomotives of all kinds now under construction and in service on American railroads to give correct data as to what can be accomplished under varying conditions by either the electric or steam method of developing tractive power, and if unwhitewashed reports of their performance can be obtained it will be of invaluable assistance to electrical and mechanical engineers generally in meeting the present and future motive power requirements."

7. "A steam locomotive in one section can be designed and placed under the control of one engineer and one fireman which will economically develop as much tractive power as may be necessary to haul the greatest amount of tonnage that can be concentrated in one train of suitable size for safe and quick handling over a division."

8. "The advantage of the electric locomotive for the handling of heavy tonnage would be from increasing the capacity of the line, and it might be that the greater business handled would justify the increased cost for installation and operation of electric locomotives as compared with steam locomotives."

9. During the discussion of that paper some of my electrical friends predicted quite vigorously that within five (5) years—i.e., after 1911—not a single order would be placed in this country for steam locomotives. In this they were correct, as not a *single* but *many* orders have since then been placed, the total purchases for use in the United States during the period 1906 to 1919 inclusive, being 39,782 steam locomotives, of which 19,489 have been ordered since 1911. Furthermore, since 1906 the average tractive power per steam locomotive in use in the United States has increased from about 24,750 to 35,000 pounds, or over 41 percent.

10. That Mr. Sprague's and my own earlier conclusions as cited were not radically wrong may be confirmed by what has transpired. For example, the New York "Tribune" has recently published a series of articles by Railroad Chairman and Presidents, on problems confronting the Carriers as regards adequate transportation facilities for the future, in which no reference was made to the necessity for any steam road electrification. Mr. Julius Kruttschnitt referred to the substitution of heavier modern for light obsolete locomotives, the elimination of every pound of unnecessary dead weight without sacrifice of strength or safety, and the conservation of fuel by the application of improvements and the education of employees. Mr. A. H. Smith referred to an electrification project for a city that would cost $60,000,000 but which would produce no revenue whatsoever. As Mr. Smith has had experience with electrification he ought to know. Mr. F. D. Underwood said that "the average man does not realize what a wonderful machine the steam locomotive is;" "that the capital expenditures involved in changing from steam to electric operation are enormous," and that "but for the notable improvements in steam locomotives which have enabled the roads to offset increased costs, they would have all been bankrupt."

11. In line with the foregoing, Mr. J. J. Hill, a few years before his death stated that the Mallet type of steam locomotive had set back the time for electrification at least fifteen years, and Mr. L. F. Loree, who made the Mallet type of locomotive in the United States an established fact and who has done as much as, if not more than, any other railroad executive to increase locomotive and freight car capacities and efficiencies has as yet been unable to determine upon any steam road divisional electrification scheme in any part of the country that is justified as compared with steam operation.

12. We all know that the foregoing named executives and railroads are representative of broad gauge policies and they do not hesitate to make improvements—when money can be procured—provided the expenditures will produce a proper rate of return in operating efficiency and economy in addition to the carrying charges.

13. From 1903 to 1917 every mountain pass controlled by the Harriman lines—and two that were studied in reconnoissance —were investigated for electrification but in no case did the operating results justify the same as compared with steam operation.

14. In the 1913 transactions of the American Institute of Electrical Engineers, pages 1845-1875, a paper on the subject of "Mountain Railway Electrification" by Mr. Allen H. Babcock, Electrical Engineer of the Southern Pacific, which related to the

proposed electrification of a district of that line which included 38 miles of 2.4 percent ruling grade between Bakersfield and Mojave, California, was published in full detail, and further the paper was placed in the hands of the engineers of two large electric locomotive manufacturers in this country with instructions to "tear it to pieces." With one exception, and which was a criticism directed to the point of view taken, rather than to the facts, by Mr. H. M. Hobart, of the General Electric Company, (pages 1256-1260 in the transactions referred to) no criticism was made of Mr. Babcock's conclusion—which was that electrification was not justified.

15. Similarly, in a report made in January, 1914, by Mr. J. P. Ripley, of the J. G. White Management Corporation, on the possibilities from the electrification of 23 miles of double track line of the Santa Fe between Trinidad, Col., and Raton, New Mexico, covering ruling grades of from 3.32 to 3.5 percent and 10 degree curvature, over Raton Mountain summit, and at which time both the use of coke oven gas at two cents per 1000 cu. feet delivered at the railway's power plant, and of purchased power were considered, electrification was not justified due to the relatively small average amount of traffic as compared with the tonnage to be moved at periods of great traffic density and on account of the savings in operation not even equalling the fixed charge brought about by electrification.

16. In line with the foregoing, several years ago a report was made on the advisability of electrifying about 275 miles, or a division, of one of the more prominent western lines, and an erroneous comparison was made, first, between the existing antiquated and uneconomical steam and an up-to-date electric operation; and second, by omitting the investment required to bring the steam operation up to date. When all involved factors were properly adjusted the net capital expenditure of $4,000,000 required for electrification compared with $1,000,000 as needed for modernizing the steam equipment, and the estimated annual operating saving of approximately $750,000 from electrification was wiped out and replaced by a saving of $250,000 from a continuation of the improved steam operation.

17. The foregoing are only a few cases where steam railway electrification projects that were thought to be entirely feasible, were, upon serious investigation, found not to be justified and indicate the caution that must be exercised in analyzing steam railroad motive power and transportation problems.

CONCLUSIONS

18. The Federal Control and Guaranty periods of the steam railroads of the country ended on February 28th and August 31st last, respectively, and these properties are again in the

hands of their owners and under the direction of the Transportation Act and the Interstate Commerce Commission.

19. Today, in consideration of the existing traffic rates and regulations as established by the Interstate Commerce Commission, and the wages and working conditions as recommended by the Railroad Labor Board, it is assumed that the railroads as a whole will average net operating earnings equal to 6 percent on their valuation as fixed from time to time by the Interstate Commerce Commission. Some railroads may earn more and some will earn less, but in the case of every line the minimum fixed charge and the maximum operating and maintenance economy will be required if the stock owners are to receive even a reasonable return on their investments.

20. In the protection and control of railroad net earnings one of the most important factors is the kind of motive power to be used, and unfortunately, in making comparisons of the relative values of steam and electric railway power, some of the electrical engineers have frequently given out such an attractive and confident line of loose figures that railway managers and their engineers have often been misled into making recommendations that have later resulted in embarrassment. In fact, references can be made to figures set forth in some of the leading technical journals during the past year that would properly be classified as a "bunch of bull" by competent engineers who have been in active railway service and seen any considerable steam and electric locomotive performances. For example, comparisons have been made; between the operations of new up-to-date electric and of obsolete steam installations; of costs of repairs per locomotive mile for electric and steam locomotives of different dates built new, and of different average ages; and of fuel rates at the sub-stations of modern central power stations with fuel rates of obsolete steam locomotives, per horsepower hour. Also assumptions have been made of extraordinary steam locomotive standby fuel losses; inclusion of steam locomotive tender, but exclusion of electric locomotive non-adhesive weight as non-revenue train tonnage; and of like erroneous factors. It is just as misleading to use as a basis for comparison the present most efficient electric locomotive operation on the St. Paul and that of its saturated steam locomotives of 1910, as it would be to compare the present most efficient superheated steam locomotive performance on the Baltimore and Ohio with its electric operation.

21. When we discuss or recommend the further electrification of the whole or any part of the 260,000 miles of steam operated railroad system in the United States, which is now making use of about 65,000 steam and 375 electric locomotives for its passenger, freight and terminal service, the most important item involved is a correct and complete statement of

facts, comparing the most up-to-date steam with similar electric operations, after which immediately come the important factors of the necessary financing and legislation.

22. To reflect initial and operating costs from a credit or an investment standpoint and to interpret faithfully on the basis of expert judgment backed by practical experience, the probable effect on the annual balance sheet, any investigation for the purpose of determining upon the advisability of electrical or steam operation for an existing or new line of railroad should be made, preferably by a committee consisting of experts in railway mechanical, electrical and civil engineering, transportation, and accounting, without an endeavor to modify the best steam railroading methods to suit the requirements of electric traction, and by keeping clearly in mind the fundamental fact that while anything within reason is possible, provided enough money can be spent, if the Auditor's annual statement cannot show the balance on the right side of the ledger the project will have failed from the most important point of view.

23. While there is much existing steam road trackage that can and should receive first consideration as regards electrification for the purpose of eliminating gases from underground terminals and tunnels, to give relief to terminal or line traffic congestion by combined rapidity and frequency of train movement in the vicinity of large commercial and industrial centers, or where transportation operations are auxiliary to mining or other industries requiring the extensive use of electricity, it would be financial suicide to electrify immediately adjacent connecting and intermediate long haul mileage, particularly in view of the improvements that can be made in both existing and new steam locomotives in the matter of reducing smoke, sparks, cinders and noise and in increasing general capacity, efficiency and economy in operation and maintenance. Without a doubt the advent of the electric locomotive has awakened the mechanical engineer, and the competition it has brought about has been one of the greatest factors in promoting the progress that is now being made in steam locomotive efficiency and economy. At the same time the electric heavy traction engineers have a wide field for the introduction of electrification on steam lines penetrating long tunnels, in busy city terminals, in dense passenger traffic zones, and for suburban traffic where the by-products of combustion are undesirable. Also on congested heavy mountain grade lines where adequate and cheap hydro-electric current may make electrification justifiable.

24. With the decreased value of gold and purchasing power of the dollar has come an increase of from 4 and 5, to 7 and 8 percent in the cost for money, which, in combination with the 100 to 150 percent increase in the cost for labor and material makes the procurement today of the most pressing railroad

capital needs almost prohibitive. Therefore, when engineers and politicians propose reckless super-power plans for the electrifying even of such belts of steam roads as lie in the densely populated district between Washington, D.C., and Boston, at a new capital cost to the railroads approximating a billion of dollars, and in addition mark off the books the principal value of existing steam locomotives, passenger cars, shops, and terminal and intermediate facilities that would be unsuitable for the electrified service, they are planning either a new road to railroad bankruptcy, or a further burden in traveling and shipping costs, or in taxes, which would be representative of criminal waste instead of increased earning capacity by means of more efficient and economical operation.

25. Furthermore, before the electric locomotive can be made permissible for general application the electrical engineer must reduce his first costs; promote interchangeability; provide a motor which will efficiently, economically and flexibly cover a wide range of speeds and not break down or deteriorate from overloading and heating; reduce complication, wear and corrosion in transmission and contact line apparatus; and substantially reduce the current losses and the liability for failure between the point of power production and the locomotive drawbar. Likewise the steam railway mechanical engineers, locomotive builders and specialty manufacturers, if they are to guard the steam locomotive and continue it in its present field of usefulness, must become more active in modernization and bring about improvements that will substantially increase its capacity and thermal efficiency by the use of higher steam pressures and superheat; compounding; more efficient methods of combustion; utilization of waste exhaust steam and products of combustion heat; better distribution and use of live steam; reduction of dynamic weights; greater percentage of adhesive to total weight and a lower factor of adhesion; and by a substantial reduction in standby.

26. As both steam and electric locomotives should have a useful life of from 25 to 50 years from the date built these policies should be inaugurated *now* by the railroad executives in order that the least artificial age will be capitalized in all new built motive power.

27. In order to determine the relative advantages of modern steam and electric locomotives the following may be stated as important items for consideration:

Legislation

28. This may be of such varied character that any assumptions for analyses purposes are out of the question.

Financing

29. The electrification of the steam roads in the United States since 1895 now embraces about 1250 road miles on 18 different lines and 375 electric locomotives, of which total about 375 road miles on nine different lines and 230 locomotives (as well as 1000 motor cars) are located in the territory between Washington, D.C., and Boston.

30. In view of past experience probably little if any financing of steam road electrification projects in the United States can be undertaken, particularly at present interest on money and labor and material prices, unless the returns are more adequately and fully guaranteed. In fact, few if any existing steam roads can justify or stand the additional capital investment required per mile of road for electrification, except for short distances under very special conditions such as prevailed on the Norfolk and Western, where the ventilation and 1.5 percent grade line features of a five-eighths mile single track tunnel restricted the train movements to a 6 mile per hour basis on a congested traffic section of the main line, and even then only providing the fixed charges and operating expenses are not too excessive.

31. The immediate requirements of new money for the more urgent steam equipment and facilities needed to provide adequate, safe and expeditious rather than luxurious service in the regeneration of the railroads, is the obvious reason for the continued utilization of the over-all more economical steam operation, and only after the possibilities in this direction have been realized can any serious financial consideration be given to the proposed radical change to super-electrification.

Adaptability to Existing Trackage and Facilities

32. First and foremost in the advantages of a continuation of the existing improved steam locomotive for all purposes for which it is permissible, is its flexibility and adaptability to existing railroad trackage and terminal and operating facilities, and the relatively low first cost at which it can be purchased per unit of power developed for the movement of traffic. Being a self-contained mobile power plant, it is possible to quickly transfer needed or surplus power from one part of the line to another and to concentrate it when and where necessary, whereas with the electric locomotive this is impossible unless electrification extends over the entire property or the sources of power supply have almost prohibitive peak load capacity. Furthermore, the various systems of electrification do not make the interchanging of electric locomotives practicable without much non-productive first-cost, complication, and maintenance and operating expense.

Effectiveness in Increasing Track Capacity.

33. Without a doubt electrification increases the capacity of a terminal and this is fully evidenced by the intensified traffic movements at Grand Central Station in New York, and at Broad Street Station in Philadelphia, but an analysis of the situation on the New York Central shows that this is not due to decreasing locomotive movements through the use of multiple units as is usually stated. For example, through line passenger trains are handled in and out of Harmon with single steam the same as with single electric locomotives, and as regards commutation service, this is largely a motor car proposition, as is indicated by the fact that as compared with 73 electric locomotives the New York Central has 241 motor cars and no trailers.

34. As already set forth, special line conditions, as on the Norfolk and Western, may make electrification advisable for short distances, but neither the results on that road nor at the New York terminals justify the frequent reference by electrical engineers to the weakness of steam locomotive haulage during the unprecedented cold weather and volume of traffic conditions during the winters of 1917-18, in that electrification would not have obviated the difficulty. If so, then why did the New Haven not operate at 100 percent of its capacity, over its electrified zone at that time? If short of locomotives or motor cars the New York Central had plenty of surplus that was not in use and which could not be utilized outside of its own electric zone on lines where it was badly needed. The probable answer is lack of interchangeability which is still one of the most discouraging operating factors involved in any electrification scheme and was fully brought out in the last report of the A.R.A. Committee on Design, Maintenance and Operation of Electric Rolling Stock wherein the wide variation of current generating, transmitting, distributing and contact systems, voltages, types of locomotives and of general ideas relating to the same sets forth the present undeveloped state of the art.

35. Furthermore, in the handling of heavy tonnage trains by the unlimited combining of electric locomotive units, the factors of peak load, transmission lines, and power plant capacity must all be considered with the probability that permissible modern steam locomotive train units can be more economically handled over dense traffic lines than the electric multiple unit super-trains. Although under the multiple unit system of locomotive and train operation it is theoretically possible to provide unlimited sustained hauling capacity, at the head of the train, the tonnage to be handled without rear end or intermediate helpers is limited by the ability of the draft rigging on the cars to withstand the pull and shock, and this limitation can be readily met and exceeded in steam locomotive design and operation, as

may be noted from the following comparison of the St. Paul electric freight and the Virginian steam **freight articulated** types of locomotives as shown in Table I.

TABLE I

ITEM	St. Paul Electric Articulated	Virginian Steam Articulated
1 Tractive power, in simple gear, maximum....	132,500 lbs	176,600 lbs
2 " " , " compound gear, "	———	147,200 "
3 " " , at 15 miles per hour.........	71,000 "	108,000 "
4 Wheel arrangement, (excluding tender).......	4–8–8–4	2–10–10–2
5 Length over all, (including tender)...........	112 ft	107 ft
6 Total wheel base, (including tender).........	102′ 8″	97′ 0″
7 Driving wheel base.........................	75′ 0″	64′ 3″
8 Rigid wheel base...........................	10′ 6″	19′ 10″
9 Total weight on driving wheels..............	448,000 lbs	617,000 lbs
10 " " " truck wheels...............	116,000 "	67,000 "
11 " " of tender (with ½ fuel and water capacity)......	———	148,000 "
12 " " of locomotive..................	564,000 "	832,000 "
13 Truck wheels—Total No....................	8	4
14 Driving " —Total No....................	16	20
15 " " —Diameter..................	52″	56″
16 " " —Adhesive weight to total......	79.4%	90%
17 " " — " " per axle, average...	56,000 "	61,700 "
18 " " —Unsprung weight per axle, average...	16,250 "	12,000 "
19 Factor of adhesion—Maximum tractive effort.	3.38	3.49
20 " " " —Tractive effort at 15 MPH	6.31	5.70
21 Source of Power............................	Electricity from outside hydro-electric plant	Superheated steam from self-contained Boiler Plant

Note—Item 16 indicates percentage of driving wheel adhesive weight to total of engine. When tender is added this figure would be 74 per cent for Virginian steam locomotive.

36. In a recent published comparison of Electric and Steam Motive Power a 100 car 5,000 gross ton freight train east-bound at Thelma, on a 0.33 percent average grade on the St. Paul, behind one of its electric locomotives, was featured, and the following is quoted: "Further instances could be cited where the benefits of electrification are badly needed and many of these are coal carrying roads, among which the Virginian Railway stands out conspicuously as a good opportunity to make both a necessary improvement and a sound investment."

37. In connection with the foregoing it may be stated that on the Virginian on October 8, 1909, a saturated steam Mikado locomotive, No. 430, of about 50,000 pounds tractive power rating, hauled from Victoria depot to Sewall's Point, a distance of 127.1 miles, against a 0.2 percent average gradient, 100

standard cars of coal and caboose weighing 7.580 gross, and 5,392 net tons of trailing load, in 8 hours-42 minutes, with 13.1 net tons of coal fired, or less than 27.2 pounds of coal per 1,000 gross ton miles.

38. Furthermore, the Virginian steam Mallets as described in connection with the St. Paul Electric locomotive on page 14 operate between Elmore and Clark's Gap, over about 13.5 miles of 2.07 percent compensated grade and through 5 tunnels ranging from 325 to 1253 feet in length, and can haul, without helper assistance, 40 cars of coal and caboose weighing 3160 gross and 2200 net tons of trailing load, in 1 hour-15 minutes, with 8.2 net tons of coal fired on 384 pounds of coal per 1000 gross ton miles.

39. Electrification was established on the St. Paul during December, 1915, and the comparisons with the Virginian, shown in Table II, as to annual operating results obtained, are of interest, and from which it would appear that the St. Paul electrification has produced no benefit, and that the Virginian steam operation is a very satisfactory one, so far as the public and the stock owners are concerned:

TABLE II

Year		1919	1918	1917	1916	1915	1914	1913	1912	1911	1910
St. Paul	Average Freight Train Load (Tons)	554	536	468	425	390	380	357	288	275	276
	Average Rate Received per Freight Ton Mile (Cents)	.92	.84	.76	.76	.78	.81	.79	.84	.84	.84
	Operating Ratio—Per cent Operating Expenses to Gross Operating Revenue	92.15	92.0	74.9	65.5	67.8	67.0	66.8	75.6	72.4	69.1
Virginian	Average Freight Train Load (Tons)	1712	1483	1508	1578	1469	1410	1111	1049	1132	809
	Average Rate Received per Freight Ton Mile (Cents)	.49	.42	.36	.34	.34	.34	.34	.35	.36	.43
	Operating Ratio—Per cent Operating Expenses to Gross Operating Revenue	76.0	77.9	57.7	52.0	58.0	55.0	57.7	61.4	59.3	69.5

40. The average freight car is in main line movement only about 10 percent of its life, or 2 hours and 24 minutes out of each 24 hours. The balance of its time can be distributed 55 percent in the hands of the railroads on account of interchanges, yard and loading and unloading track movements, surplus cars, repair tracks and road delays, and 35 percent in the hands of the shipper and consignee, due to loading and unloading reconsignment and Sundays and holidays. Therefore, increasing train speeds beyond established economic limits at the sacrifice of tonnage, and with an increase in power fuel, track and equipment upkeep and danger of operation is not the solution of the freight traffic problem. For example, an increase of 50 percent over and above the established economic freight train speeds would be only 72 minutes of the daily life of each freight car, whereas capital expenditures applied to the reduction of those delays which now involve over 21½ hours per day, or about 90 percent of the life of the car, would give much more effective and economical results.

41. As the electric locomotive is a constant speed proposition, whether going up or down grade, and is unable to utilize its rated capacity and effectiveness through the same range of speed and tractive power variations as the more flexible steam locomotive, the latter can therefore be more efficiently operated over the continually changing up and down grades, levels, curves and tangents traversed by the average freight train in this country.

42. With respect to passenger train service, where speed is more of a factor, the steam locomotive performs equally satisfactory. For example, on the main line of The Baltimore and Ohio, for a distance of 17 miles between Piedmont, West Virginia, and Altamont, Maryland, the average gradient is 2.2 percent. A single Pacific type locomotive with a tractive power of 43,400 pounds will haul up this grade, without helper, in 50 minutes' time, or at an average speed of 20 miles per hour, a passenger train consisting of nine cars weighing 620 tons without, and 830 tons with locomotive. The same train will make the trip down grade in 35 minutes, or at an average speed of 28½ miles per hour. The average total weight of engine and tender of these Pacifics is 210 tons, which may be compared with a total weight of 265 tons for the St. Paul electric locomotives which are used to handle similar passenger trains up 17 miles of 2.2 percent grade from the Columbia River west at an average speed of 25 miles per hour.

43. When it comes to excessive and expensive passenger train speeds it is only necessary to refer to the discontinued 18-

hour trains on the New York Central and the Pennsylvania between New York and Chicago, to the Philadelphia-Atlantic City service on the Reading, and to the run made in May, 1893, when engine No. 999 in charge of Engineer Charlie Hogan, on the Empire State Express, covered a mile in 32 seconds, or at the rated speed of 112½ miles per hour, which is a pattern for the electrical engineer to work to. In fact, it would be interesting to see one of the new Centipede, bi-polar, gearless type of St. Paul passenger locomotives, with its 12 pairs of 44 inch diameter driving, and two pairs of guiding wheels with extremely low centre of gravity for unsprung weight, operate at such speed or even at speeds of from 70 to 85 miles per hour, which are daily being made by large steam Pacific type passenger locomotives on various roads throughout the country.

Fuel Consumption.

44. Great economy in fuel consumption and cost is the principal claim for electrification and ever since the Presidential address at the A.I.E.E. Convention held in New York on February 15, 1918, the guardians of the steam railroads have been "fed up" on the theory that it would be possible to save at least two-thirds of the coal consumed by the then existing steam locomotives and that the useful carrying capacity of existing trackage could be increased about 10 percent by the elimination of company coal movement, if electric locomotives were substituted. In fact, eminent electrical engineers have recently arrived at the startling conclusion that had the railroads of the United States, using 63,000 steam locomotives, been completely electrified in 1918 along lines fully tried out and proved successful today, they would have required, without the use of any water or other power, only 53,500,000, instead of 176,000,000 tons of coal or its equivalent, thereby effecting a modest saving of more than two-thirds, or 122,500,000 tons.

45. The basis for arriving at these comparative figures is so obviously ridiculous that they warrant comment only for the reason of the general publicity given. For example, facts as taken from the Interstate Commerce Commission Statistics of Railways in the United States for the year ended December 31, 1918, are that a total of 3,615,697 tons of anthracite and 134,214,480 tons of bituminous coal, 1,638,956,953 gallons of oil and 72,447 cords of hard and 182,267 cords of soft wood were consumed by about 63,531 steam locomotives averaging 34,995 pounds tractive power each. This total coal, oil and wood is equivalent to about 149,106,901 tons of coal, and it cost about $500,225,205.00 delivered on the locomotive tenders. These authoritative figures immediately reduce the average of 2793 tons as stated by the electrical engineers, to an average of 2347 tons, as actually charged and used per locomotive, during the year,

and show an erroneous over-statement of a total of 28,334,726 tons, or an average of 446 tons of coal equivalent, per locomotive, per year, or a decrease of 19 percent in the stated fuel consumption that electrification would in no wise affect.

46. Again for the steam operation a coal rate of 12.75 pounds per kilowatt-hour of useful work done, as measured at the driving wheel treads, (just how this was computed is not understood) or seven pounds per kilowatt-hour (including transmission and conversion losses inherent in electrical operation) as measured at a central power station, was based on some tests made in 1910 on the St. Paul of some probably long since antiquated types of saturated steam locomotives. Then for the electrical operation a modernized central power station coal rate of 2½ pounds per kilowatt-hour in combination with a 40 watt hour rate at the point of delivery of the power to the railroad system for moving a gross ton mile of passenger and freight train was used, which would produce a movement of 1,000 average gross ton miles for 100 pounds of coal of about 12,000 BTU value per pound as fired. In arriving at these data apparently factors were overlooked or disregarded such as; gradient and curvature; drifting train mileage; human element; the necessity for hauling one-third of the freight car miles without lading and its effect on train resistance; the necessity for from 4 to 5 percent light locomotive mileage in order to meet traffic movement requirements with no trailing tonnage whatsoever as a divisor into the fuel or current used; the use of 15,000 locomotives in switching and transfer service; the existence of 25,000 steam locomotives equipped with superheaters and of 35,000 equipped with firebrick baffle walls; the past ten years' improvement in steam locomotive boilers and machinery; that electrification will not eliminate the rail haulage of company coal or of dead weight on locomotive leading and trailing truck wheels; that large central power stations will only show a fuel saving when operated somewhere near their rated capacity without peak load conditions; that the inter-connecting of electrification systems will result in prohibitive conversion and transmission losses; that electric motors must operate at predetermined loads to produce maximum efficiency; that central power stations cannot be regulated to a basis of 50 percent average load factor; and many others.

47. However, accepting the assertion that the proposed electrification will produce 1000 gross ton miles for an average of 40 kilowatt-hours, or 100 pounds of 12,000 BTU coal, as stated and generally approved by electrical engineers, what can the modern steam locomotive do to justify its existence?

48. Dynamometer car tests made by a Joint Committee of representatives of the New York Central and Pennsylvania Railroad and the American Locomotive Companies during August, 1910, of the first Mallet type of locomotive put into use on the Pennsylvania Division of the New York Central and operated over the 65 miles of average .5 percent grade line, between Avis and Wellsboro Jct., may be cited. This locomotive was built ten years ago and by no means represents the best practice of the present day when superheat has been increased and a more efficient all round machine is produced. At that time the average of six runs gave a thermal efficiency of 6.01 for the locomotive, and a test made on August 27, 1910, is representative and shown in Table III.

TABLE III

Miles run, about	65
Cars in train, No.	65
Cars in train, tonnage	3,734
Running time	4 Hrs. 35 Min.
Time on road	6 Hrs. 51½ Min.
Average speed, MPH	12.9
Thermal efficiency of locomotive	6.25%
Dry coal per drawbar horsepower hour	2.90
BTU in dry coal as fired	14,053
Cut-off	—
Drawbar horsepower	1270.4
Drawbar pull	34071
Steam pressure in branch pipe	203.3
Superheat in branch pipe	143.7
Machine efficiency of locomotive	89.21
Boiler efficiency	69.07

49. Taking now the entire New York Central with its high and low grade lines and the Pittsburg and Lake Erie with its low-grade lines and we have from the Government reports for the year 1919 the coal consumption for all freight locomotives as shown in Table IV.

TABLE IV

Railroad	Pounds of Coal Consumed per 1000 Gross Ton Miles			
	Jan., Feb., March	April, May, June	July, Aug., Sept.	Oct., Nov., Dec.
New York Central	155.0	124.6	119.0	147.8
Pittsburg and Lake Erie	104.3	82.1	77.2	95.7

50. The foregoing do not show an opportunity to bring about a two-thirds saving in fuel by electrification, and there is no doubt but that these steam locomotive performances can be substantially improved.

51. Furthermore, the 2-6-6-2 type Mallet steam locomotives of about 88,500 pounds in compound, and 106,200 pounds in simple gear tractive power, operating over a distance of about 155 miles of average rolling high-grade line with a ruling grade of 1.18 per cent seven miles long, between Birmingham, Ala., and Columbus, Ga., on the Central of Georgia, during which periods steam is used about 50 percent of the time, the locomotive drifting the balance of the time, produce a figure of 106 pounds of coal of approximately 13,500 BTU value per pound per thousand gross ton miles, and which compares quite favorably with the foregoing hypothetical figures as given for electric operation.

52. The results of some dynamometer car tests made during 1918, to which year the statements pertaining to this proposed fuel saving apply, may be of interest. At that time the steam locomotives tested were of the ordinary superheated Mikado freight type of the following general description:

Weight on driving wheels----------	110 Tons
Weight on truck wheels-----------	32 "
Cylinders, simple ---------------	25x32″
Driving wheels, diameter----------	56″
Steam pressure ------------------	200 Lbs.
Tractive power ------------------	59,600 Lbs.

53. One locomotive was fitted for hand firing and burning coal on grates, while another was equipped with the "LOPULCO" system for burning powdered coal in suspension, and the tests were made in tonnage freight service handling from 2400 to 2600 tons east-bound and from 1850 to 2250 tons west-bound on the Santa Fe main line between Ft. Madison, Iowa, and Marceline, Mo., (the profile consisting of .8 percent ruling grades) a distance of 112.7 miles, during March and April, 1918. The coal averaged from 1 to 8 percent moisture, 33 to 38 percent volatile, 51 to 41 percent of fixed carbon, 15 to 12 percent ash, 4 to 3½ percent sulphur, and from 12,055 to 11,050 BTU as fired. The comparative average results are shown in Table V.

TABLE V

ITEM	Powdered Coal Locomotive	Hand Fired Locomotive
1 Total trips run (112.7 miles each)	14	10
2 " miles "	1578	1127
3 Average running time—Hours	5.06	5.25
4 " dead time — "	1.25	1.01
5 " total time — "	6.31	6.26
6 " speed, MPH	22.3	21.6
7 " trailing tonnage per train	2278	2283
8 " gross 1000 ton miles	256.5	255.4
9 " coal per gross 1000 ton miles	82.4	114.8
10 " superheat—degrees Fahrenheit	223	173
11 " coal per boiler and superheater HP Hour	3.74	4.99
12 " BTU per pound of coal as fired, lbs.	12,025	11,160

54. As the coal supplied to the grates of the hand fired locomotive was considerably lower in heat value than that specified in the electrification project, and as the tests were run during March and April, it can be assumed from the foregoing that the average yearly performance will approximate 100 pounds of 12,000 BTU coal per 1000 gross ton miles, or equivalent to what we are promised for the expenditure of billions of dollars of new capital and the loss of billions of dollars worth of investment in existing plant and equipment to inaugurate the comforts of electrification.

55. On the Delaware and Hudson between Carbondale, Pa., and Oneonta, N. Y., a distance of about 94 miles, of which 74 miles is 0.3 percent ruling grade, their hand fired Consolidation type locomotives averaging about 65,000 pounds tractive power, will, with helper service over 20 miles of from 1.0 to 1.4 percent grade, handle freight trains averaging about 3,800 actual gross tons at an average speed of about 15 miles per hour, and with a coal consumption (mixture of 50% anthracite buckwheat and 50% run-of-mine bituminous) of about 76 pounds per 1000 gross ton miles when using a feed water heater and of about 86 pounds when using injectors (exclusive of coal used by helpers).

56. It is also not out of order to refer to dynamometer car tests which it is understood have been made on the New York Central, wherein on the basis of the same comparative thermal value of the coal, a single expansion superheated steam locomotive required, per drawbar horsepower hour, about 2.6 pounds of coal as compared with about 2.25 pounds for an electric locomotive.

57. Mr. A. Lipetz, Chief of the Russian Mission of Ways of Communication, has also presented some data relating to exhaustive tests made on Russian Railroads during the period 1908 to 1914, with simple and cross-compound types of steam locomotives with and without superheaters, which are of interest in this connection. These locomotives were of the Mogul type of approximately the following general characteristics:

Cylinders, simple, diameter	19½″
" , cross-compound, dia.	HP 19½″ LP 29½″
" , stroke	25½″
Driving wheels, diameter	67″
Steam pressure	185 Lbs.
Weight, on driving wheels	104,000 Lbs.
" , total exclusive of tender	132,000 Lbs.

58. When operated on four different divisions, with trains of the same tonnage and under otherwise like conditions the greatest fuel economy was obtained with the cross compound-superheater locomotives and successively, with the simple cylinder-superheater, cross compound-saturated and simple cylinder-saturated. In general average the cross compound locomotives showed a saving of about 17 percent as compared with the simple, and the superheater locomotives showed a saving of about 21 percent as compared with the saturated, while the cross compound-superheater locomotives showed a combined saving of about 35 percent as compared with the simple-saturated locomotives.

59. The Russian Railroad results from cross compounding and superheating are confirmed by the performance obtained from similar equipment applied to various types of locomotives on various railroads in this country and Canada from time to time, and as there are now about 65,000 steam locomotives in the United States, of which probably 62,000 have simple and only 3,000 have compound cylinders, and of which total only about 25,000 are as yet equipped with superheaters, the foregoing indicates what steam locomotive fuel savings are still possible merely through the application of cross compounding or superheating, or these combined factors.

60. Just as the Interborough Rapid Transit Company has found it possible to bring about a saving of from 15 to 20 percent in current consumption by means of coasting recorders as a check on the human factor, so can the proper organization and field supervision, checking and education reduce the fuel losses, wastes and consumption of the existing steam locomotives and

the increasing cost of coal and oil will no doubt bring about early and extraordinary savings and economies in that direction, from the source of fuel supply to the stack, to the end that 1000 BTU's of fuel fired will produce greater thermal efficiency than ever before. That this is entirely practicable may be confirmed by some tests made under the direction of Professor Goss at the Altoona Testing Plant of the Pennsylvania Railroad some years ago, when in a series of steam locomotive tests he reduced the dry coal fired per drawbar horsepower hour from 5.2 to 3.9 pounds, or about 33 percent, by merely substituting experienced for inexperienced firemen.

Efficiency of Locomotive Operation

61. The off-setting fuel and energy losses, due to standby in the steam operation, and decrease in efficiency on account of fluctuating loads in the electric operation must not be lost sight of. Neither should those incident to the transforming, transmission and conversion of electric current and like factors be neglected.

62. It is unquestionably true that when operating under ideal fixed load conditions, the central power station, either hydro-electric or steam, can produce a horsepower with less initial energy input than is possible on a steam locomotive. It is also true that the standby losses on existing steam locomotives are, in ordinary practice, a serious proportion of the total fuel consumption, but it is likewise a fact that the majority of these can be substantially reduced if not entirely overcome, by modernizing the present equipment and improving maintenance and operation, which would then rob the electrical engineers of their main argument in favor of a blanket electrification.

63. While the electrical engineers and manufacturers in this country deserve great credit for the progress made in the development of the electric locomotive, they have as yet been unable to design one which can operate at maximum efficiency throughout its range of load. The point of maximum efficiency being well established and fixed, and the current curve on an electric motor not being flat, any over or under-load from the predetermined maximum efficiency load increases the current consumption. Furthermore, when, on account of transportation conditions a motor is required to carry an overload for periods of five or six hours, it either breaks down due to heating or otherwise requires special power consuming auxiliaries or long rest periods for the dissipation of the heat stored within itself due to the resistance of the current through the wiring, to permit of continuous operation.

64. However, what the steam engineer is unable to reconcile in electric locomotive design, is such radical departures in one year's time as have taken place in the St. Paul electric passenger locomotives, as may be noted from Table VI.

TABLE VI

Railroad	ST. PAUL	
No. of locomotives	5	10
Year put into service	1920	1920
Class of service	Pass.	Pass.
Driving wheels, No.	24	12
" " , Diameter	44″	68″
Weight, total locomotive, pounds	530,000	550,000
" on driving wheels, "	458,000	336,000
" " guiding wheels, "	72,000	214,000
Tractive Power, 1-Hour rating, forced vent.	46,000	66,000
" " Continuous rating, forced vent.	42,000	49,000
Speed, Hour rating, MPH	26.4	22.7
" Maximum safe, MPH	65.	65.
Factor of adhesion, 1-Hour rating	9.98	5.09
Kind of Drive	Direct	Geared

65. Instead of a serious effort toward efficiency, economy, standardization or interchangeability, practically every mechanical and electrical detail in these two lots of five and 10 each locomotives produces radical engineering changes, and the factor of adhesion of 9.98 indicates an enormous amount of driven dead weight. In fact, there are 346,000 pounds in each of the five, and 286,000 pounds in each of the 10 locomotives, or more than the weight on the engine and tender trucks of a steam locomotive of like capacity, that are not needed to provide the required adhesion and which necessarily must be charged to the electrical apparatus.

66. Furthermore, to produce, at various hydro-electric or steam power plants, electric current at say 6600 volts AC, step the same up to 100,000 volts AC, connect and transmit it from 100 to 300 miles through transmission lines to switching substations located approximately 30 miles apart, step down to 2300

volts AC, and then convert into direct current at say 3000 volts for locomotive use, involves expensive lines, plants and equipment, as well as tremendous losses from the generator at the central power station to the bus bar on the direct current side of the transformer, where the current is usually metered for billing. Also the secondary system, involving the distribution lines between sub-stations and the secondary line made up from the bonding of the rails or of a copper secondary line returning to the station, as well as the losses through the motors and the machine friction of the electric locomotive itself, are responsible for further losses in current, all of which, after allowing for say 10 percent regeneration, not only limit the capacity of the electric zone but also materially increase the arbitrary electric costs usually considered, so that it is safe to say that the actual dead loss in power from the central power station to the electric locomotive drawbar will be not less than 50 percent.

67. In some of the published and confidential reports relating to the St. Paul installation the only item of electric losses taken into consideration was between the high tension bus bars at the sub-station and the input to the motors on the locomotive, the losses between these two points being approximately 37 percent. With the sub-stations on the St. Paul spaced approximately 30 miles apart, and with 3,000 volts, there is a 600 volts drop between sub-stations under normal operation, and this is further increased by the power limiting apparatus which is designed to keep down the peak load. Therefore, the entire structure of estimated costs of comparative electric and steam operation seems to have been based on figures obtained after the power had been generated, transformed and transmitted, and the losses due to the various steps incident thereto neglected.

68. The number of factors entering into an analysis of the net thermal efficiency of the electric locomotive, in terms of drawbar pull, are so many as to make it impossible with the lack of dynamometer car and laboratory test data, to arrive at a figure which is not based on a number of assumptions; but as a matter of interest, assuming that *all of the factors are affected equally* in the electric locomotive, the net thermal efficiency at the drawbar, when taking into consideration the boiler, engine, generator, step-up transformer, AC transmission, step-down transformer, AC-DC converter, DC transmission, motors, and machine efficiencies may, as representative of average existing practice, be illustrated as in Table VII.

TABLE VII

Equipment	Net Thermal Per Cent	Load Rating Per Cent 100	75	50
Boiler	Factor	—	—	—
	Efficiency	76.7	76	72
Engine	Factor	(18.25)	(18.29)	(19.17)
	Efficiency	14	13.9	13.8
Generator	Factor	(90)	(89.5)	(86)
	Efficiency	12.6	12.44	11.88
Transformer, Step-up	Factor	(98)	(96)	(90)
	Efficiency	12.34	11.93	10.67
Transmission, AC	Factor	(90)	(95)	(97)
	Efficiency	11.10	11.32	10.34
Transformer, Step-down	Factor	(98)	(96)	(90)
	Efficiency	10.87	10.85	9.30
Converter, AC to DC	Factor	(80)	(75)	(63)
	Efficiency	8.69	8.13	5.85
Distribution, DC	Factor	(90)	(95)	(97)
	Efficiency	7.82	7.71	5.66
Motors, DC	Factor	(91.5)	(90.8)	(89.5)
	Efficiency	7.15	7.00	5.05
Machine Drawbar	Factor	(81)	(85)	(90)
	Efficiency	5.79	5.95	4.54

69. Likewise the net thermal efficiency of existing representative steam locomotives, in terms of drawbar pull, may be illustrated in Table VIII.

TABLE VIII

Equipment	Superheated or Saturated Steam	Net Thermal Per Cent	Load Rating Per Cent 10 0	75	50
Boiler	Superheated	Factor	—	—	—
		Efficiency	42.7	54.9	65.9
	Saturated	Factor	—	—	—
		Efficiency	45.0	57.4	70.0
Cylinders	Superheated	Factor	(11.9)	(11.0)	(10.5)
		Efficiency	5.08	6.04	6.92
	Saturated	Factor	(7.8)	(8.4)	(7.8)
		Efficiency	3.51	4.82	5.46
Machine Drawbar	Superheated	Factor	(75)	(80)	(85)
		Efficiency	3.85	4.83	5.88
	Saturated	Factor	(77)	(80)	(82)
		Efficiency	2.70	3.86	4.47

70. Comparing the electric and steam locomotive figures as illustrated in Tables VII and VIII, the relative percentage of power delivered at the track rails to 100 percent BTU in the coal would be as per Table IX.

TABLE IX

Kind of Locomotive	Net Thermal Efficiency at Load Ratings of		
	100 Per Cent	75 Per Cent	50 Per Cent
Electric	5.79	5.95	4.54
Steam, Superheated	3.85	4.83	5.88
Steam, Saturated	2.70	3.86	4.47

71. As 100 percent load rating conditions would, in practice, occur only momentarily and as the majority of the drawbar load represents from 30 to 60 percent of the locomotive maximum drawbar capacity, comparison should properly be made only of the net thermal efficiencies at 50 percent load ratings.

72. As a check on the foregoing figures relating to steam operation, the tabulation of various laboratory dynamometer test performances of representative types of steam passenger and freight locomotives is presented as per Table X.

TABLE X

LABORATORY DYNAMOMETER TEST PERFORMANCES OF REPRESENTATIVE TYPES OF STEAM LOCOMOTIVES.

KIND OF LOCOMOTIVES	Speed in Miles per Hour	Thermal Efficiency of Locomotive — Percent	Dry Coal Consumed per Drawbar Horse-power Hour — Lbs.	B T U in Dry Coal as Fired	Cut-off — Percent of Stroke	Drawbar Horse-power — Lbs.	Drawbar Pull — Lbs.	Steam Pressure in Branch Pipe — Lbs.	Superheat in Branch Pipe — Degrees Fahrenheit	Machine Efficiency of Locomotive — Percent	Boiler Efficiency — Percent
	10.78	3.4	5.3	14,140	86.3	1273.0	42,284	186.0	182.01	93.73	44.88
Consolidation Freight	14.38	5.3	3.6	13,330	63.4	1437.4	37,502	195.9	210.25	87.15	64.06
46,290 Lbs.	17.97	5.9	3.2	13,330	50.0	1516.6	31,518	196.6	200.64	91.53	61.00
Tractive Power @80%	21.56	5.8	3.3	13,330	41.7	1423.1	24,645	195.3	188.46	87.19	59.33
Boiler Pressure	28.75	5.3	3.6	13,330	42.3	1534.0	19,924	189.1	193.93	83.83	56.13
	30.50	5.7	3.3	13,330	38.6	1459.0	17,835	195.4	185.03	80.46	60.64
Mikado Freight 54,587 Lbs.	18.90	7.34	2.64	13,122	33.3	1167.6	23,115	180.0	195.0	88.2	75.09
Tractive Power @85% Boiler Pressure	25.70	6.14	3.17	13,090	59.3	1994.9	29,128	168.0	260.0	89.8	67.15
Mikado Freight	7.2	5.5	3.3	13,947	60.9	945.4	48,962	199.5	137.4	89.60	68.37
57,850 Lbs.	14.5	5.9	3.1	13,937	62.3	1794.1	46,460	193.6	168.7	94.51	60.23
Tractive Power @ 80%	22.0	6.4	2.8	14,044	52.9	1941.3	33,198	194.4	152.6	89.79	64.67
Boiler Pressure	29.3	6.4	2.9	14,044	52.4	2130.9	27,331	193.0	163.7	87.44	65.43
Decapod Freight	10.9	6.31	3.0	—	20.6	809.3	27,744	248.9	160.5	80.66	74.14
90,000 Lbs.	14.7	8.10	2.4	—	30.5	1472.9	37,623	246.7	201.9	82.93	80.49
Tractive Power @ 75%	21.8	6.4	3.0	—	40.7	2634.5	45,134	236.1	246.3	91.67	56.38
Boiler Pressure	29.0	6.0	3.2	—	42.4	2533.8	32,748	234.3	268.4	81.19	60.72
	27.98	7.14	2.51	14,207	39.6	1260.5	16,893	194.2	214.26	87.03	80.46
Pacific Passenger	37.31	7.11	2.52	14,207	35.2	1382.8	13,899	192.8	229.54	83.11	78.96
30,700 Lbs.	55.90	8.10	2.20	14,504	20.9	1037.9	6,958	200.4	176.20	74.60	84.60
Tractive Power @80%	65.13	7.61	2.27	14,735	29.8	1781.7	10,258	189.8	240.66	84.68	71.78
Boiler Pressure	74.43	6.80	2.54	14,724	23.5	1542.7	7,772	192.4	222.77	75.88	69.27
	83.74	3.06	5.80	14,350	38.5	1682.6	7,535	180.5	262.44	65.39	40.71
	28.38	6.72	2.67	14,185	54.7	2213.0	29,245	191.4	192.1	94.69	66.97
Pacific Passenger	37.84	7.47	2.32	14,702	46.2	2057.1	20,388	194.1	182.3	89.88	71.15
41,845 Lbs.	47.30	6.23	2.78	14,702	44.5	2230.9	17,687	191.0	184.2	87.07	62.24
Tractive Power @80%	56.76	6.46	2.68	14,702	46.4	2367.3	15,642	189.4	200.4	86.35	66.20
Boiler Pressure	66.22	7.47	2.37	14,379	42.7	2392.0	13,547	193.4	200.7	88.68	72.95
	75.84	5.25	3.42	14,185	50.7	2518.0	12,478	185.8	209.1	85.94	54.94
	85.32	6.46	2.74	14,379	38.9	1888.8	8,320	194.3	197.1	70.99	75.11

73. It will be noted that at speeds of from 15 to 75 miles per hour the existing superheated steam locomotive thermal efficiency actually ranges from 5.3 to 8.1 percent as compared with the calculated figures of from 4.83 and 5.88 percent for 75 and 50 percent load ratings, respectively. Adding to this an increase of from 15 to 50 percent in net thermal efficiency that may be produced from developments now under way and the steam locomotive of the future will be quite a respectable assembly of engineering efficiency.

74. In a report made by the Hydro-Electric Power Commission of Ontario, on February 15, 1918, on the rate of coal consumption in 73 electric generating stations and industrial establishments in Canada and the United States, ranging from 150 to 150,000 kilowatts capacity, the following average figures are given as per Table XI.

TABLE XI

Average Size of Station Capacity		COAL			Load Factor	Efficiency in Conversion of Heat Energy in Coal to Electric Energy at Switchboard
		B.T.U. per Pound	Pounds per			
KW	HP		KW Hour	HP Hour	Per Cent	
650	870	12,500	7.65	5.70	29.3	3.5
2,980	4,000	12,900	4.30	3.20	34.2	6.2
7,230	9,700	11,900	4.07	3.04	31.7	7.0
24,600	33,000	13,600	2.91	2.17	36.0	6.6
96,000	128,800	14,000	2.01	1.50	36.9	12.1
149,000	199,500	13,500	1.92	1.43	44.7	13.1
46,340	62,600	13,600	3.81	2.84	35.5	8.4

75. Comparing the foregoing with the laboratory test data on steam locomotives, it will be noted that the thermal efficiency at the switchboard of the largest stations is only about double that of the average steam locomotive at the drawbar.

Cost for Enginemen

76. When the use of the electric locomotive was contemplated it was thought that a single motorman could be substituted for the steam locomotive engineer and fireman. Under existing conditions this is neither permissible nor practical, and as each electric locomotive must carry a man comparable to but who does not function as a fireman, his wage is an added expense without economic return and must be charged to the cost of firing the central power station boilers or otherwise distributed.

Cost of Maintenance

77. In determining the maintenance cost of the electric locomotive the popular error is to take into account the locomotive proper, whereas a true comparison can only be made by including all corresponding elements as found in the self-contained steam locomotive which goes back to the upkeep of all facilities having to do with the utilization of the fuel or water power, including the central power station buildings; boilers; engines; conversion, transmission, distributing and contact line systems; sub-stations; track rail bonding and insulation; electric disturbance cut-outs or neutralizers; extra expense in upkeep of the electric zone trackage; and like auxiliaries and finally the electric locomotive itself.

78. With particular reference to the maintenance cost figures that have been given out as applying to the New York Central, Michigan Central, Pennsylvania and St. Paul railroads for the years 1913 to 1918 inclusive, and which range from $3.78 to $10.87 per 100 locomotive miles run, these no doubt apply to the electric locomotive units only, and if so would appear exceptionally high even for relatively new built steam locomotives. While it is true that during the first few years of life the expense for maintenance of electrical equipment is low, after that time the deterioration of the insulation necessitates constant testing and renewal, which entails great expense and delay to say nothing of frequent failures and partial or complete destruction. Consequently until a true reflection of the investment interest, depreciation, taxes and insurance and the upkeep cost per electric locomotive mile and per 1000 gross ton miles hauled, can be given by including all the factors and elements of age and mechanism that are embodied in the steam locomotive, all comparisons will be worthless.

Peak Load Conditions in Relation to Traffic Requirements

79. With the steam locomotive the traffic requirements are met by the distribution and utilization of the necessary number of self-contained motive power units as required, regardless as to the capacity of one or more central power stations or of any limitation in quantity, or in price, of the total available power output. The operation of one or of 500 steam locomotives at their maximum capacity at any given or for any duration of time on a single division, is of no concern.

80. However, in order to meet the ideal conditions for electrification, the traffic should be uniformly spread or scattered over the 24-hour period, whereas in the majority of cases train movement is based on traveling and shipping conditions and cannot be advanced or delayed in order to eliminate peak load

conditions. That this cannot be done in order to maintain a straight line power demand can be illustrated by citing the condition that exists in any large industrial center where freight accumulates and is switched during the day period and the out and inbound train movements concentrate in fleets, principally in the evening and morning, respectively, and cause peak load requirements at those times. To contemplate a change in industrial working hours or conditions, or in the movement of livestock and perishable freight in order to overcome these limiting and troublesome peaks by equalizing the movement would be out of the question.

Ease of Starting Trains

81. Due to the uniform torque as developed by the electric locomotive, its adherents have laid great stress on its ability to start a heavier train than a steam locomotive of relatively the same tractive power and factor of adhesion. In steam railroad service the locomotive is seldom required to start "the train" but what it does is to start each car in the train, successively, and which nullifies this theoretical advantage of the electric locomotive. In fact, with steam locomotives of the Mallet and other types having compound cylinders equipped with properly designed simpling devices the starting power is increased about 20 percent as compared with electric locomotives of equivalent road rating.

Rate of Acceleration

82. In order that the desired running speeds may be reached in the minimum of time after the starting of trains, the ability of a locomotive to rapidly accelerate its load is of considerable importance and in this respect the electric power has had the advantage. The steam locomotive engineer has, however, not lost sight of this fact and improvements already made in boiler and cylinder horsepower ratios, as well as developments now undergoing for the utilization of existing non-productive adhesive weight and to increase the co-efficient of friction between the propelling wheels and the track rails will enable the steam locomotive to duplicate the performance of its electric competitor in this regard.

Train Braking

83. Since the development of regenerative braking with the electric locomotive, great emphasis has been laid on the increased security of operation over heavy grade lines due to the ability of the locomotive to hold the train under complete and positive control on the down grade without breaks, by temporarily converting the main motors into generators to produce electricity

which is returned to the line for use by some other locomotive in pulling a train. Considerable attention has also been directed to the saving brought about through the elimination of the ordinary air braking on such down grades.

84. The Baltimore and Ohio has, with steam locomotives, successfully and safely handled its heavy tonnage and dense traffic on the Cumberland and Connellsville Divisions for many years with the ordinary air brake equipment, and this tonnage descends a grade averaging approximately 2.2 percent for 17 miles, at an average speed of from 15 to 20 miles per hour for freight, and from 25 to 30 miles per hour for passenger trains, without slow-downs or stops. This performance is comparable with that on the worst grade conditions in the St. Paul electrified zone, and while an increase in the capacity of freight cars to as high as 120 tons, as those now in use on the Virginian and Norfolk and Western, makes the factor of train braking an important one, the use of the improved light and loaded car air brake equipments solves that question in a safe and efficient manner.

85. While the regenerative system of braking can probably be developed to a point where it can be safely used without the train air brake, it is problematical as to what economy will result, as evidenced by the recent serious accident on the St. Paul wherein a heavy tonnage freight train made up with an electric locomotive at the head end and a steam Mallet helper locomotive at the rear end, broke away from the latter and derailed the entire train of about 65 cars on a 20 mile grade of 2.2 percent, due to the failure of the regenerative brake control. When the power so generated cannot be directly used by another pulling locomotive on the line, it must be otherwise absorbed, and it remains for the electrical engineers to prove just how much of it is lost in conversion or by absorption and the resulting net gain as compared with the investment, fixed charge and upkeep and operating cost for the equipment involved.

Effect of Weather Conditions

86. Even though the full steaming capacity, horsepower and drawbar pull of a modern steam locomotive can be developed during cold weather conditions, there are the factors of radiation and freezing to be reckoned with, which gives the electric locomotive the advantage in winter, particularly, as its effectiveness is greater on account of the lesser tendency for the motors to overheat. This winter advantage, however, is largely overbalanced during the summer when the main motors heat, especially under overloads, and require cooling at terminals or otherwise overheat and result in insulation break-downs or burn-outs, or other troubles.

87. Anyone using the electrified service of the New York Central or the New York, New Haven & Hartford out of Grand Central Terminal is aware of the noise from the continual use of blowers for cooling the transformers and main motors when locomotives are at rest, and of the insulation troubles which are not only the cause for delays and fires, but for the destruction of entire locomotive units and the complete tying up for hours of the dual railroad system traffic pending relief by steam locomotives.

Road Delays and Tie-Ups

88. While the electric locomotive has the advantage of not being required to take on fuel and water, except for the operation of steam heating equipment for passenger trains, with the increased capacity of the modern steam locomotive tenders, and the lower water and fuel rates per drawbar horsepower developed, the delays due to taking on these supplies have been greatly reduced and need not be serious. Delays in taking water have long since been entirely eliminated through the use of track troughs, and with modern fueling facilities either coal or oil can be quickly supplied, where necessary, between terminals.

89. While the hours of service law; points of origination, gathering, classification, distribution and interchange of traffic; and like factors, rather than the distances that individual locomotives can be run, regulate the distance of solid train runs without breaking up and re-classification, still the modern steam locomotive is not seriously lacking as regards continuous and monthly mileage capacity. In fact, in view of steam locomotive mileages obtainable, i. e., from 400 to 600 miles per round trip, and from 10,000 to 12,000 miles per month, no less an authority on, and promoter of, modern constructive steam railroads than Mr. L. F. Loree, contemplated as early as 1903 the running of through fast freight trains between Baltimore and Chicago with single pulling locomotives, assisted by helpers as necessary, over ruling grades. Mr. Loree's idea was to make a steamship operation of a locomotive and freight train, but the difficulty in working out satisfactory engine and train crew arrangement, and not the inability of the steam locomotive to make the run, was responsible for the abandonment of the project.

90. However, a demonstration along this line was recently made by the Baltimore and Ohio when a train of 70 empty coal cars leaving Jersey City on July 11th at 12:30 A. M. reached Rockwood, Pa., at 9 o'clock the next morning, the train movement of 415 miles having been accomplished in 32½ hours, or at a speed of about 307 miles per freight car per day.

91. Barring collisions, wrecks and like accidents not due to the system of motive power in use, steam operation is not sus-

ceptible to complete tie-ups as is the case with electrification, where short circuits or failures occur due to rains, floods, storms and like causes, and as the result of motor, wiring and insulation heating, deterioration and break-downs, as the individual mobility of each piece of motive power without regard to any outside source of power enables quick relief. This has not only been repeatedly demonstrated on the New York Central, New Haven, and Long Island electrified sections, but in several instances it has resulted in serious stoppage and congestions of traffic, the most notable of which was that on the New Haven in December and January, 1915-1916, when on account of a blizzard, steam locomotives had to be substituted for the entire electrical operation, due to break-down of the communication and control system and the failure of insulators, grounding arcs and short circuits in connection with the over-head transmission and feeder lines.

Terminal Delays

92. The examination of reports of a dense heavy freight traffic railroad in the Eastern District shows the time of its steam locomotives for a recent two months' period distributed as follows:

1. In road service ______________________ 50 % of total time
2. At terminals, awaiting trains and otherwise in hands of Transportation Department ____________________ 26.4% of total time
3. At terminals in hands of Mechanical Department ____________________ 23.6% of total time

93. There is no doubt but that the electric has an advantage over the steam locomotive as regards time required for periodical boiler work, fire cleaning and rebuilding, fueling and watering except where fuel oil is used, but where terminal delays occur due to waiting for trains, such as the foregoing statement sets forth, the time required for such work does not become an expensive determining factor in the daily average miles to be obtained per locomotive. Also the fact that the electric locomotive cannot, without terminal rest periods or otherwise the consumption of power to operate auxiliaries, operate at its maximum capacity, must not be overlooked. Furthermore, many improvements in the fuel and ash handling and combustion equipment of the steam locomotives using coal are now in process and terminal delays due to these causes, as well as to lack of proper engine house facilities for quick despatchment, are annually being reduced by improved means and methods.

94. With the establishing of more scientific and careful methods of designing, testing and inspection, and the more extended use of safety appliances, the failures of steam locomotive boilers and machinery, particularly those resulting in personal injury, are relatively low as compared with the work performed. It is therefore doubtful if there is any greater proportion of risk from the steam locomotive in that regard than from electrocution and other attendant dangers from high voltage electrification.

Discussion of Papers
on the
Relative Advantages of Modern Steam and Electric Locomotives

BY MR. GEORGE GIBBS

Chief Engineer, Electric Traction, Long Island Railroad

October 22, 1920.

In discussing this subject it is permissible, I presume, to view it from the standpoint of either design or performance. It concerns the relative advantages of two kinds of power plants for conducting railway transportation.

In steam service the plant is a part of the moving train; in electric it has both stationary and moving elements, *viz.,* a central power-generating plant, various connecting links to bring the power to the train, and means of utilizing it there.

As regards simplicity, therefore, the self-contained steam locomotive has an inherent advantage over the combination of elements required for electric propulsion, and the latter must show some peculiar advantages in an *operating,* rather than a *structural,* sense if it is to supersede steam traction. Furthermore, the steam locomotive has been developed to a perfection of detail and a high degree of steam economy during the one hundred years of its use; it does wonderful work, and is in possession of the field, representing a heavy money investment and can, therefore, be displaced (even by something better) only by slow degrees. So I think railway men can discuss this new rival of the steam locomotive with calmness and should cooperate with our enthusiastic electrical friends in giving their suggestions a trial; you never can tell what good may develop out of a thing, especially when one does not fully understand its possibilities. I speak as a steam railway man—that was my bringing up, and I confess to a sneaking fondness for the reliable old "iron horse," and may be pardoned for frankness. But I am also sufficiently "in" with the new order of things to make plain speaking to my electrical friends proper and to suggest to them due modesty in making their claims. We want cooperation of both sides in the development of a useful new traction means. This is especially desirable now, as the paramount necessity of the country is more and better transportation. If it can be furnished through electric traction, in particular cases as a starter, we should know it now.

I cannot go into technical details tonight, but I think our electrical friends will concede, and mechanical men must, in light of sufficient evidence furnished by existing installations, that an electric system will function in a successful, reliable and efficient manner for any kind of railway service. It is capable of unlimited hauling capacity, is flexible as to speed and has

important features conducing to safety in handling trains. It is, however, to the fundamental question affecting its adoption which I wish to draw attention. "Is the substitution of electric for steam haulage warranted by its advantages in the production of more transportation, and if so, is it practicable financially?" No sweeping generalization to the effect that electric traction will be used because it functions well will impress railway managers; they must have the answer to the above question.

Now, as regards the first portion of this query, it would appear that there are a number of important situations in which electric traction will produce results which cannot be had by the steam locomotive, notably in increasing existing track capacity, especially on lines having heavy grades, in yard shifting, in suburban and terminal services, and in locations (such as in tunnels), where the absence of combustion is necessary or desirable. Such installations should be undertaken if financially feasible, and this can only be determined by a critical examination of each case. Assuming that the money can be raised for an improvement which will pay, it will be found that electric traction will pay, directly or indirectly, in the special cases to an extent depending upon the density of traffic and the difficulty of maintaining proper steam operation. It must be admitted that an electric installation involves a higher first cost than for steam, in fact, its adoption means that more or less existing investment must be scrapped, therefore, the increase in fixed charges must be offset either by the direct operating savings produced or these plus the indirect savings and benefits. The latter may mean avoidance of permanent way additions, a permissible change in operating methods, more traffic moved, and new kinds of traffic produced. The direct savings have been under discussion tonight; in spite of some difference in opinion, I think we cannot escape the conclusion that there is always a large saving in fuel with electric traction, generally some saving in maintenance cost of "power equipment" and often important savings in train crew costs, engine house expenses, minor supplies, etc.

Sometimes these "direct" savings will be sufficient to return a handsome profit over and above charges; if not the indirect savings must be included. It will avoid future disappointment if we face the facts; the electrification of the railways of the country as a whole, or the electrification of the whole of any extensive component system, is neither practicable nor desirable, measured by costs and results; the doom of the steam locomotive has not been sounded and will not be in our time. But the fact that electrification is not universally applicable should not discourage anyone; it has a very large and profitable field (both for the railways and the manufacturers). These facts indicate the importance of carefully investigating each proposed application to insure that it is properly conceived and carried out.

Discussion of Papers

on the

Relative Advantages of Modern Steam and Electric Locomotives

By Mr. A. W. Gibbs

Chief Mechanical Engineer, Pennsylvania System

October 22, 1920.

I have read with much interest the papers on steam versus electric operation of railroads, and cannot but feel that both Messrs. Muhlfeld and Armstrong have been a bit too enthusiastic. Both methods of operating have their advantages and both have decided limitations.

In Mr. Armstrong's case his data is largely derived from mountain electrification, where the electric locomotive is undoubtedly at its best and the steam at its worst, and he has compared with it a type of steam locomotive whose coal and water rate is more than double that of locomotives which are especially designed for such service. Then on this mountain performance he reasons from the particular to the general application of electric operation. True, he puts in a disclaimer as to the particular steam locomotives referred to representing the best modern practice, which brings up the question—Why cite them at all?

It is not at all certain that the speed advantage claimed is by any means true where the steam locomotive is designed for the work.

On page 3 he gives a comparative statement of the performance of two steam and one electric locomotives to which exception can be taken because the steam locomotives do not represent the last word as to those available, and the electric locomotive is on paper.

I submit data for a 2-10-0 type steam locomotive of which over 100 are in regular service and of which, fortunately, very full information is available from the locomotive testing plant. These locomotives were expressly designed to do all of their work within the economical range of steam distribution, the required power being obtained by increases in size of cylinders and steam pressure. While I have given the power at nearly the speed mentioned by Mr. Armstrong, the performance is excellent at double the speeds given, but the sacrifice in drawbar pull—from nearly 60,000 pounds at 14.7 miles per hour to about 43,000 pounds at 25.3 m.p.h.—would not be justified. The figures given are within the range where stoker firing is as economical as expert hand firing, with the additional advantage that the stoker does not get tired.

This is a special design in which the advantage is that it cannot be worked at uneconomical points of cut-off. At speeds and pulls where the usual design is also worked at an economical range its performance is about the same.

2-10-0 Type Steam Locomotive.

Weight in Working Order	371,000	pounds
Weight on Drivers	342,050	"
Weight on Engine and Tender	523,000	"
Drawbar Effort at 14.7 miles per hour, 45% cut-off	58,900	"
Gross Tons (2% grade)	1,280	
Trailing Tons	1,019	
Coal per D.H.P. at this speed and cut-off	2.8	
Tractive Effort at 22 miles per hour, 40% cut-off	42,500	pounds
Gross Tons	923	
Trailing Tons	662	
Coal per D.H.P.	3.2	
Tractive Effort at 25.4 miles per hour, 45% cut-off	43,600	pounds
Gross Tons	948	
Trailing Tons	687	
Coal per D.H.P.	3.8	

The Mallet performance given in Mr. Armstrong's paper is evidently that of one of the large compound locomotives. In all of these locomotives there is a tendency to choke up with increases of speed, due to increase of back pressure.

The same arrangement of limited maximum cut-off used in the 2-10-0 locomotive already described has been embodied in a simple Mallet now running. This locomotive has the same speed elasticity as the 2-10-0 type. Unfortunately, this Mallet, which has a tractive power of about 130,000 pounds, cannot be tried out on the present locomotive testing plant. Its drawbar pull is also above the capacity of the dynamometer car, so that no definite figures can be quoted until new recording springs have been applied and the machine calibrated.

In brief, the improvements in the steam locomotive, if properly availed of, have much narrowed the field of economical electrification.

Stand-by Losses. While these losses are actual and large it is very difficult to fix their value, as they are so much affected by the use made of the locomotive. Where the average monthly mileage is low the stand-by loss is presumably high, and it is a part of good operation to bring up the average mileage as high

as possible. When all is said the electric locomotive has still an advantage with respect to stand-by losses, provided there are sufficient trains in motion to smooth out the total demand on the power plant, which is assumed to be steam operated.

Weather. The independence of the electrical locomotive of severe weather is another undoubted advantage, not so much because of the performance of the motors, but rather from the avoidance of losses and delays due to ash-pit work and to frozen pipes and other parts, incidental to the presence of water on the steam locomotive. Where cold weather is a steady winter diet, this is usually better handled than where cold spells are spasmodic.

Liability to Interruption. Electric operation is dependent on uninterrupted connection with the source of power. In the event of breakage of the line, especially of the overhead construction, the trains in the section involved are dead and cannot get themselves out of the way of the repair trains. On large systems it is customary to make great changes in the assignment of locomotives to clear up congestion at any point on the system; also, to avail of diversion routes on which steam trains may be moved around obstructions on the main line. The fact that the steam locomotive is a self-contained power plant is an immense advantage in this respect. In electric operation there is not this freedom of movement.

Speeds. The question of speed is evidently treated from the freight standpoint, for there has never been any question as to the speed capacity of well designed passenger locomotives, being far beyond that permitted by the rules.

In this connection it may be said that many of the electric locomotives could be very much improved by closer adherence to steam standards as to distribution of weights and in the adoption of wheel arrangements, which will not set up resonant disturbance at high speeds.

While Mr. Armstrong treats the question of speed from the meeting point of view, it is probable that electrification will have its greatest application on roads where the traffic is dense, probably on multiple track roads. As I see it, the feature of high speed of trains is of less importance than uniformity of speeds of different trains. If tonnage trains had the same speed as preference trains, and could thus avoid the great delay due to side tracking of trains of inferior rights, far more would be accomplished than the mere saving in time over the division due to the increased speed. With steam trains at 25 miles an hour water may be picked up from track troughs. Coaling stops will, however, still be necessary. Delays due to the train itself, by which I mean hot boxes, burst hose, broken coupler knuckles, etc., would occur equally with steam or electric operation.

There are some figures in Mr. Armstrong's paper which are not clear—for instance, on page 3, tractive power at 18 percent.

is given for three locomotives. The value of these figures is not evident, and it cannot be admitted that a fixed coefficient will apply to different types of steam locomotives. Up to a certain point the tractive effort is governed by the cylinder and wheel dimensions, beyond which point the boiler capacity rules. The data given is too meagre for checking. By the same token it may be asked whether the tractive effort of the electric locomotives is anything more than the multiplication of the driver weights by the same fixed coefficient. If so, the rest of the figures in the same table are aerial for all the locomotives.

I fully agree with Mr. Armstrong that the 1,000-ton-mile has absolutely no value as a method of comparison for different roads, and it should not be used except possibly for comparing the same division at different periods.

The table on page 13 appears to contain numerical errors, and there is the same objectionable fixed coefficient which may or may not be true. It is an inexact figure at the best and would put a premium on piling up useless dead weight on drivers. The only comparison which has any value is the record of an accurate dynamometer car.

Cost of Maintenance. On page 5 is given maintenance cost per mile for different electric locomotives. Any figures of post war dates are so clouded by the abnormal labor and material costs as to be very doubtful. These locomotives have not run long enough to reach a general level of costs as it will be noted that the average annual mileage is low except in the case of the Milwaukee locomotive. Besides this, there is no evidence as to the maintenance costs of the rest of the outfit, including power plant, transformers, transmission lines, converters or transformers, trolley or third-rail, and track circuits, all of which are essential to the operation of electric locomotives, and are just as much a part of the electric locomotive as the boiler is of the steam locomotive. If current is purchased the purchase price, of course, includes the cost of maintenance of the power plant and of the transmission line to the point where the current is received on the road. If it is generated by the using company the cost of maintenance of the power plant should be included with the cost of maintenance of the locomotives. The renewals of parts of the power plant and transmission lines do not occur in the early stages of operation, but they are certain to come and when they do are heavy. From experience, I must deny that the back shop can be dispensed with, with either class of locomotive, though it is admittedly more essential in the case of the steam locomotive.

Extent of Electrification. Where electrification is contemplated a very serious question is: What shall be its extent? Naturally the desire would be to wipe out as many as possible of the extensive accessories to steam operation. If, however, it becomes necessary to operate steam trains over the electrified

section, it will obviously be necessary to retain water stations and possibly fuel stations, provided the electrified section is sufficiently long. This operation of steam locomotives under their own power over electrified sections would be necessary in case of redistribution and possibly in case of diversions where the electrified section formed part of the diverted line. Therefore, the claim for economy in doing away with these features of steam operation would probably not be realized.

Mr. Muhlfeld's Paper. In my judgment, Mr. Muhlfeld's enthusiasm has carried him too far in minimizing the advantages of electrification. The operation of the electrified roads has undoubtedly been good, whether it be terminal or road operation. The reduction in the number of engine terminals alone is a great advantage, to say nothing of the absence of fuel and water service with the stops that they entail, the way to get trains over the road being to keep them moving.

He also ignores the fact that the modern improvements which have so added to the performance of the steam locomotives are potential only. For instance, it is very possible and common by indifference to so carry water in the boiler that the superheater becomes merely a steam dryer and its value disappears. In many cases because of neglect of damper mechanism or from dirty flues little benefit is derived from improved appliances. Modernizing of steam locomotives calls for intelligent use of the devices, which will come when the old spirit of loyalty returns.

Conclusions. The electric locomotive or electric operation has in many cases undoubted operating advantages because the power is generated in quantity at few sources and the power on any one train is not limited by the capacity of a self-contained portable power plant; sustained speeds are possible due to independence of fuel and water stations and, as a result of both these conditions, better use can be made of a given stretch of road.

Electrification does not at all obviate the numerous class of delays due to the train itself, such as hot boxes or other of the numerous derangements which when combined so much retard the movement over the road.

Electrification does not obviate that class of delay arising from necessary classification on line of the road to meet terminal requirements. Where the terminal conditions limit the capacity of the road as a whole electrification is not the remedy.

On level grade roads where the existing steam locomotives will handle all the cars that can be safely moved in one train, the value of electrification will be principally the absence of stops and probable reduction in overtime.

The claims for fuel saving have been greatly overstated by not making comparisons with the potential performances of the best steam locomotives.

Of course, with steam locomotives the maintenance or the indifference of those operating them, both on the road and elsewhere, may to a large extent nullify the savings possible.

Stand-by losses must exist probably with both classes of operation, but especially with steam, and may be any percentage of the total consumption, depending on the actual use of the locomotives.

The relative cost of repairs of both classes of equipment cannot be fairly stated at the present time because maintenance conditions are so abnormal and because the most modern locomotives of both classes are too new to have reached a stable condition, this being especially true of the electric one. While the indications are that the maintenance of the electric locomotive will be less than that of the steam, it must be remembered that the electric locomotives are dead affairs without the necessary electric generating, transmitting, converting and track appliances, all of which are an added expense, due solely to electrification; hence the cost of maintenance of all of these, in addition to that of all of the locomotives, divided by the locomotive mileage, is the real treasury cost of maintenance per locomotive mile.

If the operating current is purchased, obviously the cost of maintenance of generating apparatus and of all appliances to point of delivery of current is covered in the rate, but in any event, it is ultimately paid in some form by the user.

Personally, I believe that many roads now operated by steam will be operated in whole or in part electrically, but that this will not be decided in the off-hand manner advocated by some.

It is to be noted that practically all of the electrification on steam railroads so far has been based on local conditions. In the electrifications in and around cities a moving cause has been the elimination of smoke and other objectionable features incidental to steam operation, and the possibility of increasing the capacities of the passenger terminals. On the Milwaukee road it was the utilization of available water power. On the Norfolk & Western it was to secure increase in capacity on a congested mountain division with tunnel complications. It is fair to assume that other electrifications will be similarly governed by local conditions.

If, after careful consideration of the road, based on actual train sheets for the heaviest actual or probable congested operation; the capacity and number of active and available locomotives required; crediting the operation with incidental savings which may be effected, and eliminating expenses peculiar to steam operation; it appears that there would be economy in electrification, either from actual savings or better operation, or both, it still remains for the management to decide whether the money required can be spent to better advantage for electrification than for some other features of the general operation.

In this connection it must be remembered that on originating roads a considerable part of the locomotive assignment is

devoted to services on the branches feeding the main line and forming part of it, and that in this service they make little mileage. If these branches are electrified, their operation will be a decided drag on the economies of the main electrification, for the reason that each of the steam locomotives will have to be replaced by an electric one with its greatly increased first cost with small use to justify. If they are not electrified and the operation of the district is part steam and part electric, locomotive terminals, organizations, and all that goes to make up steam operation must be retained to an extent.

Discussion of Papers

on the

Relative Advantages of Modern Steam and Electric Locomotives

By Mr. W. L. Bean

Mechanical Assistant, New York, New Haven & Hartford Railroad

October 22, 1920.

The volume of data and arguments presented in the several papers is so great and the field of the subject so extensive in scope that discussion in the permissible allotment of time must be quite general or at least include few details.

One cannot escape the fact that the prime factor to be considered in any engineering enterprise of commercial nature is the economic result of the entire specific project. Results of sub-projects in themselves are important and consideration sometimes of a multitude of factors of minor or more than minor nature must be sufficient, even to the last detail, but partisanship in championing some of the sub-factors to the exclusion of others is undesirable and, of course, does not represent the best of engineering procedure.

It must be conceded broadly that electrical operation requires less coal per unit of traffic handled than steam operation. How much less depends on the specific conditions.

Likewise, the mileage per unit of electric equipment is ordinarily greater per unit of time. On one largely electrified road express locomotives average 27% more miles per day per locomotive owned than steam power in similar service. However, the first cost of the electric engines per unit of capacity was 84% greater than in the case of steam. Therefore, the fixed charges are greater for the electric engine per unit of service.

A few words respecting comparative flexibility, especially in service of a character which demands it, may be of interest. A certain modern passenger electric locomotive will handle a heavy train of Pullmans at high speed on a through run with few stops such as would require a modern Pacific type steam engine of about 43,000 lbs. tractive effort. However, to operate the electric engine in heavy local service over the same distance is impossible because of the heating caused by frequent starting. In such service, the maximum train which can be handled by the electric locomotive can only approximate what can be handled by a steam engine of about 30,000 pounds tractive effort.

There is not much elaboration of the fact that an inconsiderate or over-ambitious yardmaster may overload the electric engine and that machine, possibly in sympathetic endeavor to

live up to the expectation of its sponsors, goes after its job like a spirited horse. A steam locomotive, on the other hand, being what might be termed more phlegmatic, and possibly realizing that its best days may be over, will do about so much and no more, and either stalls or loafs over the road without injury to itself. Not so with the electric engine. It may not be subject to "creeping paralysis," but since it leads a strenuous life, it acquires a sort of hardening of the arteries in the way of accumulative depreciation of insulation, which leads the way to heavy repairs.

Realization of the extent of accumulation of wear and tear, both electrically and mechanically, makes it difficult to understand just how railroads are to maintain electric locomotives without back shops unless they job the work out to manufacturers of electrical equipment. Bearings wear, springs fail, axles and frames break on electrics as much as they do on steam engines. Switch groups, transformers, motors, both main and auxiliary, air compressors, blowers, control and collector apparatus, all require overhauling periodically. Officers in charge of maintenance of electrical equipment on one Eastern road are at present insisting that $350,000 be expended soon for an addition to the present back shop.

Regarding the design of the machinery of a steam locomotive being utterly circumscribed by the necessity for tying it up to a steam boiler, the statement can be made that some modern high powered electric locomotives are so compact with apparatus, both inside the cabs and beneath, as well as on top, that additions to, or enlargements of details, even of a minor nature, are well nigh impossible. Furthermore, this is not peculiar to AC-DC machines.

When one comes to attempting the solution of the problems attendant on the heating of passenger trains, electrically drawn; to find room for the boiler, water and fuel oil storage, auxiliaries, etc., and keep within weight limitations, the difficulties are very real and certainly lead one to the conclusion that on electric passenger power, the boiler is circumscribed by electrical apparatus.

It may be inconsiderate to remark that electrical engineers on one road have even advocated the construction of a tender for carrying the boiler water tanks, etc. Imagine an electric locomotive requiring a tender. What about the expense and annoyance of either turning the engine or switching the tender at terminals? What about costs, initial, operating and maintenance? What about dead weights hauled around and what about possibly additional attendance cost? Surely some figures may have to be re-vamped.

In surveying electrification broadly, one finds there is a vast field of opinion among electrical engineers as to types of installations. Is it possible that by so many widely divergent electrical means the final net results are always to the discredit of steam operation? Can any type of electrical layout beat

steam? Even if so, it is hardly probable that each electrical arrangement can be as good as every other one.

It appears that when a railroad goes in for electrification, it must settle on some type of layout, the main characteristics of which are fixed. Extension must either be along the original plan as to power characteristics, distribution or collector apparatus, or else vast sums must be spent to re-vamp the existing plant if the new layout is not to be largely separate and independent with all of the inherent disadvantages of non-interchangeability and lack of flexibility.

The steam locomotive, except in a moderate way as to clearances and weight limits, has a wide range of application. Railroads loan steam power back and forth with advantage usually to both parties, but no case comes to mind where electrical equipment for heavy traction can be interchanged.

The design and operating characteristics of steam power have developed far more along lines of possible common usage and practice. It is to be hoped that the lines of development of electrical facilities will tend to converge rather than diverge too widely.

Some reasons for such desirability are —

(a) Railroad Managements will not be so fearful of becoming tied up with a heavy and inflexible type of investment, which may quickly become obsolete through not lending itself reasonably well to extension or modernization.

(b) The need for a broader field of design and manufacture of equipment and the furnishing of repair parts for the same.

Dependence largely on one manufacturing concern which must unload heavy overhead charges at sur-charge rates, unheard of in the case of steam locomotives, is highly undesirable and is restrictive to the extension of electrification.

CONCLUSIONS

Study and comparison of the details item for item, of any large activity, is necessary in order to get the benefit of real analysis, but satisfactory conclusions as to the merits of the entire project cannot be reached by setting up in a partisan way outstanding advantages on the one hand any more than by listing all the disadvantages on the other.

Certain more or less intangibles are important and must be weighed impartially. Among such are the increase in real estate value through electrification, increased capacity of road, comparative safety and reliability of operation, permanence of type of design, obsolescence and depreciation factors, etc.

Tangibles from a money standpoint can and should be segregated and set up in full scope on both sides of the case and conclusions based on the net result at the bottom line of the

balance sheet. If fixed charges on plant, including equipment, plus maintenance charges, plus other out-go, outweigh the savings in fuel, plus other operating savings, the net result is a deficit and all manner of proclaiming isolated pecuniary advantages would not induce a careful investor to support the enterprise.

Discussion of Papers

on the

Relative Advantages of Modern Steam and Electric Locomotives

By Mr. W. F. Kiesel, Jr.

Mechanical Engineer, Pennsylvania Railroad

October 22, 1920.

Mr. Shepard speaks of the transportation problem as a most serious one, the movement of traffic having fallen far behind, and expresses his belief that electrification is bound to be the most potent factor for its relief.

For electric locomotives he claims greater power, speed, flexibility and mobility; intimates that under electric operation divisions can be made much longer; and electric locomotives can be built to take any train which will hold together over any profile, at any desired speed, limited only by condition of track and car equipment.

The same claim can truthfully be made for the steam locomotive.

For either kind of operation, the length of divisions and location of terminals are governed by other than locomotive limitations, or, at least, there is no valid reason why any features of either electric or steam locomotives should affect the location of, or distance between, terminals.

In power, speed, flexibility and mobility, either type can furnish all that track and car equipment will permit. To illustrate this, your attention is directed to three recent locomotives: One built by the General Electric Company, for the Chicago, Milwaukee & St. Paul Railway, and described in the General Electric Company Bulletin, No. 44,102, according to which it has a starting drawbar pull of 115,000 pounds, and a drawbar pull of 56,500 pounds, at 25 miles per hour on a 2 per cent. grade; the other two were built by the Pennsylvania System—one is an electric locomotive, having two synchronous speeds (10 and 20 miles per hour), and the other a steam locomotive, with four simple cylinders.

Both Pennsylvania System locomotives have a drawbar pull, in starting, on level tangent, of 135,000 pounds. On grade the effect of truck and tender weight of the steam locomotive shows its influence, and the net drawbar pull, at 20 miles per hour at rear drawbar (calculated), of these locomotives is as follows:

	Electric	*Steam*
On Level	81,000	83,375
½ Per Cent. Grade	78,000	80,250
1 " "	76,000	77,125
1½ " "	73,500	74,000
2 " "	71,000	70,875

Furthermore, the steam locomotive can deliver more net drawbar pull than the Milwaukee electric locomotive, at any speed up to 50 miles per hour, and on any grade that it would have to encounter.

The strongest coupler in use to-day (American Railroad Association, type "D") has an elastic limit of about 200,000 lbs. On present equipment there are several million couplers of a strength inferior to this. Therefore, it would scarcely be advisable to build locomotives of greater pulling capacity than two-thirds of the elastic limit of the strongest coupler, or 135,000 pounds.

Mr. Shepard mentions retirement of weaker car equipments, which no doubt is advisable, but will require time.

The sentence, "Every other industry that has been electrified has experienced a revolution in methods and service, due to electrification," invites the most careful thought of those contemplating a change in operation.

Will electric service produce greater returns?

Can the revolution in methods and service be accomplished without serious handicap during the transition period?

The capital investment for electric service will be more than five times as much as for steam service.

The cost of an electric locomotive is about twice as much as that of a steam locomotive of the same power.

The electric locomotives have shown some saving in repairs over steam locomotives, but, after ten or twelve years service, they require rebuilding, especially in the electrical equipment, which runs the total cost of repairs beyond that of the steam locomotives. Possibly this can be improved.

From the report of the Commission which investigated the advisability of substituting electricity for steam, in Chicago, it appears that the maintenance cost for wages and material would be 30 per cent. more for electric operation than for steam. This is offset, at least partially, by electric traction advantages of regeneration, no re-forking of ballast to remove smoke stack cinders, and less wheel and brake shoe wear, etc.

With the exception of three factors: First, capital investment; Second, coal per drawbar horsepower; and, Third, standby losses, there is too little difference between the two, for operation in open country, for further consideration.

Mr. Shepard speaks of one locomotive as a generator of power, and the other as a transformer of power coming from

central stations with many refinements and high thermal efficiency. He credits the best steam locomotive with an average coal consumption of twice that of electric operation, for the same work performed.

The Pennsylvania System steam locomotive referred to has the same steam distribution system as that of a 2-10-0 locomotive, which has been fully tested on the Locomotive Test Plant (See Pennsylvania System Test Bulletin No. 31), and will burn no more coal per drawbar horsepower. The average coal consumption per drawbar horsepower of the locomotive tested on the plant was 2.7 pounds, for all firing rates up to 100 pounds per square foot of grate per hour, and 3.27 pounds for all firing rates from 100 pounds to 160 pounds per square foot of grate per hour. Locomotives seldom have to burn more than 100 pounds per square foot of grate per hour. These steam locomotives had no feed water heaters, the use of which—as proven by other tests—would reduce the amount of coal per drawbar horsepower appreciably.

Inquiries were sent to various electrified roads—not including those with only short transmission terminal operation—requesting the average cost in coal per K.W.H. at the power plant, the average efficiency of the transmission line from power plant to the locomotive, and the average efficiency of the locomotive.

One road, which has been electrically operated a number of years, and records each month's operation, shows a power plant cost of coal per K.W.H. of 2-5/8 pounds as the minimum when the plant output is maximum. Taking this as 100 per cent. load factor, they show a cost per K.W.H. of 3.2 pounds of coal for a load factor of 50 percent., and 3.53 pounds for a load factor of 40 percent. Most of the monthly record figures lie between 35 percent. and 50 percent. load factors, and the grand average of coal per K.W.H. is above 3¼ pounds. These figures necessarily reflect both the daily and monthly variations in load factors, and are, therefore, high.

Another road reports 40,000 to 44,000 B.T.U. per K.W.H. at switchboard, for coal varying between 13,000 and 14,200 B.T.U. per pound.

The coal used in the test of the 2-10-0 steam locomotive given above averaged 13,429 B.T.U. per pound.

Replies as to the line efficiency appeared inconsistent, therefore, the data given in "Power and Maintenance Cost on the St. Paul, by Renier Beeuwkes," in Railway Age, page 237, of August 6th, 1920, is cited. This shows an average ratio of net input at locomotive *to* actual system input *for* locomotive of 66.3 for the Missouri division, and of 68.3 for the Rocky Mountain division. Replies as to locomotive efficiency indicate that this is less than 75 percent. in all cases.

Apparently the fluctuations in load factor present a greater menace to coal economy than steam locomotive standby losses. The average load factor may be taken at 50 percent. Neither

line efficiency or locomotive efficiency are likely to average as much as 75 percent.

Existing installations may be taken as approaching, but not yet equal to, three pounds of coal of 13,500 B.T.U. per pound per K.W.H. at power plant, a line efficiency of 75 percent, and a locomotive efficiency of 75 percent., resulting in a consumption of four pounds of coal per drawbar horsepower hour. Therefore, the standby and other losses of the steam locomotive can be 32.5 percent. to equal the probable best average performance of present day electric traction in coal consumption, and that much loss would be a sorry reflection on operating methods.

Possibly improvements already contemplated, or that will spring up later, may change this situation, but until actually ready to do the work as cheaply as the steam locomotive, it is illogical to tear up the old operation by the roots and substitute a much more costly plant whose habits are not so well known.

Mr. Armstrong also dwells on greater power, speed, flexibility and efficiency, and speaks of running a thousand miles with no attention, except by crews, and describes ideal characteristics of a locomotive, none of which apply to the electric locomotive in any greater measure than to a steam locomotive. The "precedent and prejudice" to which he refers seems to be imaginary. As he uncovers step after step of his flights of imagination, a gradually increasing desire for "facts" is felt.

In view of existing locomotives described in the foregoing, the table of comparisons between two steam locomotives — a Mikado at 14 miles per hour, and a Mallet at 9 miles per hour (evidently not good specimens), and an imaginary electric locomotive at 16 miles per hour—is, to say the least, inconsistent, and the claim that a mountain division will have an increase of 50 percent. in daily tonnage over POSSIBLE steam engine performance is not so "modest" as claimed.

In this statement the claim that "electric locomotives can be maintained for 20 to 25 percent. of the upkeep cost of steam locomotives" should be included.

Two statements in the fuel comparison deserve some analysis. The standby losses for steam locomotives are given as 9,042 pounds of coal. The regenerative braking on the electric locomotive is credited with a saving of 1,430 pounds of coal. About half, or 4,595 pounds of coal, of the standby losses are for making fire and drifting, which is high. The coal used for making fire is not all loss. In ordinary service there will be no regeneration on upgrade, or on level, and probably none on down grades of less than ½ percent. On steeper down grades the regenerative current must buck the line current. Returning 18 percent. of current used, back into the line, appears high, and leads to the suspicion that Mr. Armstrong uses a comparison between a very bad steam operating condition, with a very good electric operating condition, which is not representative of averages. At present, steam locomotive standby losses are high,

but, when railroads get back to normal, these losses will be materially reduced, and the average will no doubt be less than 15 percent. of the coal used. Regeneration may be a slight factor, but it will be nearly negligible in averages.

For certain local conditions, electric traction should be given priority rights, even if the cost is greater. They are:

1. In tunnel operation.
2. In large cities and their suburbs.
3. Where sufficient water power is available.
4. Where super-power plants can be built in juxtaposition to an adequate supply of culm, or other low-grade combustible not easily marketable.

In the open country, where smoke and gases from the stack are not seriously objectionable, existing installations do not yet indicate that electric traction can be carried on with as little coal consumption as modernized steam traction.

If the problem arises to replace an installation consisting of steam locomotives which are too small and inefficient, larger and more economical steam locomotive units, to meet any power and speed requirements within the limitation of track and equipment, can be substituted for the smaller units without in anyway interfering with the continuity of traffic or educating the personnel to handle the new power.

As tersely stated by Mr. Shepard, the substitution of electric traction will require a revolution in methods and service.

The answer to the problem is governed by whether there is a saving in coal with electric traction over that with steam traction, including standby losses, and whether this saving is sufficient to pay interest, depreciation, taxes, insurance, etc., on more than 400 percent. greater capital investment, and for the interruption of traffic and the revolutionizing of the organization during the transition period.

Paper by Mr. J. E. Muhlfeld, which was received after the foregoing was completed, could not be digested in time to compare his analysis with that herewith.

Altoona, Pa.,
October 18th, 1920.

Discussion of Papers

on the

Relative Advantages of Modern Steam and Electric Locomotives

By Mr. R. M. Brown

Engineer of Motive Power, New York Central Railroad.

October 22, 1920.

The subject is one which involves many factors which I am not fully prepared to discuss and therefore can only comment upon some of the things which have been said here tonight.

Figuring the cost of maintenance or operation of steam vs. electric locomotives. In the steam locomotive we must maintain and operate a complete power plant, whereas, in the electric locomotive, we merely have the tractor. However, in computing comparative costs—either from maintenance or operating standpoints, it seems absolutely necessary that consideration must be given to the proper proportion of the cost of operating the central power plant in electric service and also the cost of transmission of power.

One of the most important phases—if not the most important—is the matter of cost based upon either one of two things: existing conditions or the situation 15 or 20 years hence. The railroad to-day must pay 7% interest on money and capital expenditure involved in the construction of power plants, substations and electric transmission lines, which would be so enormous as to almost be out of the question.

Mr. Armstrong has suggested certain things which the Train Dispatcher might be able to accomplish with electric locomotives. If the present steam locomotives could be removed from the rails and replaced with electric locomotives of equal capacity, what would the experienced Train Dispatcher be able to accomplish? Assuming that capacity means equal maximum drawbar pull in starting and that all track and other facilities and conditions remain the same, it seems to me just a question of how often the electric locomotive could deliver the goods at the other end of the line without delay or failure as compared with what the steam locomotive now does.

If the electric locomotive can be made to run 1,000 miles without change and will never fail or break down or its power become diminished as often as the steam locomotive, the Dispatcher might accomplish a great deal even with present cars, track facilities, etc., but there is more involved than merely replacing a Mikado or Mallet locomotive with an electric locomotive of equal capacity.

A 60,000 lbs. weight per axle and the possibility of adopting higher loads for electric locomotives on account of the absence of unbalanced forces is referred to. I wish to mention that the rail and wheel wear are also important factors which must be considered in increasing wheel loads.

It is stated that there is no need of the back shop for electric locomotives unless turning tires or painting may be considered heavy repairs. I am sure that shops (whether they call them back shops or some other name) will be required. Electric locomotives must be heavy and drop pits, cranes and other shop facilities will be required even for running repairs. The quick substitution of repair parts always in stock and ready to apply would be an advantage, but no one can tell how many different kinds of parts would be required for the different kinds and types of electric locomotives which would exist after 15 or 20 years of electric operation, involving thousands of locomotives. Furthermore, the spare parts or repairs would have to be made in shops maintained by the Railroad Companies or by outside concerns.

A comparison is made of maintenance costs of the electric vs. steam locomotive amounting to 60c per mile for a steam Mallet, as compared with 14.65c for the C.M. & St. P. electric. In checking up some cost figures on a N.Y.C. division which uses Mallets for most of its heavy freight trains, the cost of repairs in the years 1918 and 1919 amounted to from 21c to 25c per mile. These figures, of course, included some simple locomotives in operation of the same division. I was able to obtain some further figures covering back shop repairs of Mallet locomotives on two different divisions for the year 1919, averaging approximately from 12c to 19c per mile. The engine-house maintenance cost is not readily available, but it is fair to assume that it could not be more than the shop cost per mile. Therefore, the total cost for the Mallet locomotive, including shop and engine-house repairs, would be from 24c to 37c per mile, or considerably less than 60c. No information is given showing just what items were taken into account either for the steam or electric locomotives in figuring the cost per mile, and any such statement cannot be fairly compared unless all items taken into account are shown.

It has been stated that electric locomotives cost possibly 50% more than steam for equal driver weight, etc. In 1917, five modern 4-8-2 type freight locomotives cost about $205,000. I understand that one C.M. & St. P. electric locomotive cost about the same amount. The five steam locomotives had a total maximum tractive effort of about 250,000, whereas the one electric had only 115,000 maximum tractive effort. Assuming that the one electric could do the work of two steam locomotives, its cost would be equivalent to five steam locomotives.

I believe Mr. Shepard has correctly stated that the electric locomotive in its present service should be taken only as indicative of what may be accomplished in the future—in fact, he

admits it is only a beginner. Mr. Shepard has suggested that the solution of the railroad problem lies to a large extent in railroad electrification. This may be true, but undoubtedly the solution lies in obtaining the money to build—more than the electrification or any other factor.

He also suggested that with the present standards of train make-up, classification and terminal handling, the electrification would double the capacity of any railroad, and as methods are improved, this capacity should be doubled again, thus securing four times the present capacity. I am sure that the electrification part of the solution is only one factor and perhaps not the greatest one involved in accomplishing what Mr. Shepard sees in the future.

It is stated that with the electric operation, it should easily be practical to greatly increase the speed of freight trains almost to that of superior trains, such as Passenger. This undoubtedly means that improvements in freight cars and freight car design must be made before passenger train speeds can be safely improved.

I wonder if any wrecking outfit or relief train problems have been solved for the electric railroad. In case of a serious wreck where trolley lines or third rails were torn up, a section of the track would be out of commission and power units which could operate independently of the trolley or third rail would have to be provided. Several trains might be turned in the zone which could not move under their own power. Undoubtedly, it will be said that in due course, all of these problems can be worked out under the electrification scheme, but whatever they are, it will cost money which will have to be charged to the operation of the electric railroad.

Mr. Armstrong's paper contains a statement indicating that the Mikado locomotive burns 158 lbs. of coal per 1,000 ton miles. Some recent figures on one of the N.Y.C. principal main line divisions show a fuel consumption varying from 125 lbs. to 130 lbs. of coal per 1,000 gross ton mile in freight service. In passenger service, the figures show from 12 lbs. to 17 lbs. of coal per passenger car mile. The figures for the freight train fuel consumption are therefore about from 28 lbs. to 30 lbs. less than those used by Mr. Armstrong in comparing the Mikado locomotive with an electric.

Editorial in the October 28, 1920, issue of Engineering News-Record.

Steam Railroad Electrification

Discussion last week at the joint meeting in New York of sections of the national societies of mechanical and electrical engineers brought out several striking aspects of the present status of steam railroad electrification. The three principal

papers, extracts from which appear elsewhere in this issue, and the discussion that followed. While the advocates of electrification made a strong case out of the probable failure of the steam locomotive to keep pace with growing demands for sustained high tractive effort at greater speeds on dense traffic zones, few engineers will be ready to relegate the steam locomotive to the scrap heap.

It is generally conceded that the large capital outlay, and the problem of disposing of steam equipment, with all its accessories, are the strongest barriers against electrification in the present state of the art. To offset these are operating economies and increases in traffic capacity from electric operation. As one authority has stated the case, "It seems to be a race between the cost of fuel and the cost of electric equipment"—which is particularly pertinent where an economical water power is available.

Possibilities for further development of steam-locomotive capacity and efficiency cannot be overlooked since their influence is to defer the time when it may be necessary to scrap existing steam accessories—including most of the elements of present engine terminals.

It has been said that the Mallet locomotive has postponed electrification for fifteen years.

Other radical departures in steam-locomotive practice, looking to considerably increased range and efficiency without exceeding limitations of clearance and wheel loading, have been proposed, and were commented upon editorially in *Engineering News-Record* of Dec. 11-18, 1919, p. 975.

New emphasis has been laid on the lack of available comprehensive cost data in present comparisons of actual operation, taking into account the almost innumerable factors that must enter. While it may require years of further practice to establish such complete data, there is reason to believe that much information based on actual experience to date does exist, but has not been made generally available. If this is the case it is to be greatly regretted.

The ultimate test must be whether the balance sheet, over a sufficient period of time, shows red or black at the foot of the column, regardless of operating luxuries, but taking into account all capital costs:

The investor must be satisfied. For example, double tracking must frequently be resorted to, even though electrification would accomplish the same object as a temporary expedient.

Studies that have been made for electrifying certain western mountain grades did not enter to any extent into the meeting, last week, but throughout the discussion there was recalled the principal points of those studies upon which agreement has been most difficult and upon almost any one of which the decision might hinge. Broadly, these include the questions:

What is the highest practicable load factor than can be attained?

What will be the cost of maintenance of all electrical equipment and of track as compared to steam operation?

On what basis will existing steam equipment be disposed of and written off?

Shall electric power be purchased or produced by the railroad and what will be the cost of current per kilowatt-hour?

What are the practicable limits of multiple-unit electric-locomotive operation for the purpose of hauling heavier trains at higher speeds without increased crews?

How many electric locomotives will be required to replace a given tonnage of steam locomotives?

In each one of these questions—and there are many others of great importance—there has been much disagreement. In a study for electrifying a mountain grade of a western line, one estimate showed a net return on net investment of only one-seventh of that indicated by another estimate for the same area, and not enough by half to justify electrification. The discrepancy was largely accounted for by wide disagreement in answers to the questions enumerated. With the present lack of available cost data from actual operation, conjecture, even though judicious. is necessarily an all too potent factor.

We heartily endorse the statement of Mr. Muhlfeld last week that further electrification studies should be made without prejudice and by joint committees composed of civil, mechanical and electrical engineers, and also representatives of the transportation and accounting departments.

The greatest credit should be accorded those who have developed heavy electric traction to its already remarkable state.

Steam railroad electrification can be expected to make important gains in the next decade, but first of all in such special cases as tunnels, busy city terminals, suburban traffic, mountain grades and dense traffic zones.

For the present and for some time to come the steam locomotive will hold its own for general service.

Editorial in the October 29, 1920, *issue of Railway Age*

Relative Advantages of Modern Steam and Electric Locomotives

Elsewhere in this issue will be found a report of the joint meeting on November 22 of the New York sections of the American Society of Mechanical Engineers and the American Institute of Electrical Engineers and the Railroad Section of the A. S. M. E. The subject considered was "The Relative Advantages of Modern Steam and Electric Locomotives." The meeting was addressed by advocates of both steam and electric traction and its importance lies in the fact that the two sides

appeared in what was practically a joint debate on the subject of steam railroad electrification. We fear that most of the large audience in attendance went away with the same opinions with which they came. The difficulty was that there was such a great bulk of material presented that it was impossible to assimilate it.

The majority of the papers were presented by ardent advocates of steam or electric traction who gave little or no consideration to the point of view of the other side. It is most unfortunate that a meeting so well launched did not result in the crystallizing of some of the vast amount of high grade data available. Here was an occasion in which the advocates of electrification found themselves on the same side of the fence and yet so much did they adhere to generalities and lay themselves open to criticism that they failed entirely to gain their point. They were fortunate, however, in that the advocates of steam operation did not take advantage of this fact or themselves take care to avoid the same faults. It is to be regretted that the discussion of electrification should be carried on in this way.

A perusal of the papers will bear out this conclusion. The electrification advocates were again guilty of making unfair comparisons. Thus one of the speakers did not hesitate to compare the operation of modern electrical equipment on the Chicago, Milwaukee & St. Paul with the results that were obtained many years ago on that road with Prairie type locomotives. He did admit, however, that this was not an absolutely fair comparison and said that operation with modern Mikado locomotives might show different results. On the other hand, one of the advocates of steam operation was unkind enough to compare the train loading on the Virginian Railway with that on the electrically operated divisions of the St. Paul. He did not draw attention to the fact that the Virginian carries bituminous coal almost exclusively whereas the St. Paul's traffic is of a very miscellaneous character not conducive to heavy train loading. These are only two examples of many such that might be mentioned.

Apparently the advocates of electrification do not yet realize how greatly the efficiency of the modern steam locomotive has been improved in recent years. Some may refer to the railroads' conservatism. The burden of proof is on those who make that statement, for the rapidity of the replacement of wooden by steel cars, the enlargement in the capacity of all kinds of cars and locomotives, the introduction of automatic block signaling, etc., are certainly not signs of conservatism.

The electrification advocates apparently do not realize the nature of the sales problem before them. They have long since sold electrical engineers in all lines of industry. At present they are trying to sell the general public. It would seem, however, that the real buyers in this sales campaign are the railroads. The present task of the advocates of steam railroad electrification may properly be said therefore to be the selling of their

idea to the hard-headed railroad executives and operating men. These men were brought up and educated under steam operation. They are, however, open-minded to the value of electrification and ready to spend large sums of money, if it is available, and if it can be shown that such expenditure will result in sufficiently lower operating costs to make such expenditures advisable. The advocates of electrification, in their presentation, made little, if any, progress in this direction; indeed neither side showed a real appreciation of the necessity of basing its argument on simple, sound economics.

November 1, 1920.

To the Editor, Railway Age,
Woolworth Building, New York, N. Y.

Dear Sir:

Referring to your editorial on the "Relative Advantages of Modern Steam and Electric Locomotives" on page 732 of the October 29, 1920, issue.

> "On the other hand, one of the advocates of steam operation was unkind enough to compare the train loading on the Virginian Railway with that on the electrically operated divisions of the St. Paul. He did not draw attention to the fact that the Virginian carries bituminous coal almost exclusively, whereas the St. Paul's traffic is of a very miscellaneous character not conducive to heavy train loading. These are only two examples of many such that might be mentioned."

As I was apparently the only advocate of steam operation who referred to the Virginian at the Joint Meeting in question, I quote from my address as presented, as follows:

> "Electrification was established on the St. Paul during December, 1915, and the following comparisons with the Virginian, as to annual operating results obtained, are of interest and from which it would appear that the St. Paul electrification has produced no benefit, and that the Virginian steam operation is a very satisfactory one, so far as the public and the stock owners are concerned:

Year		1919	1918	1917	1916	1915	1914	1913	1912	1911	1910
St. Paul	Average Freight Train Load (Tons)	554	536	468	425	390	380	357	288	275	276
	Average Rate Received per Freight Ton Mile (Cents)	.92	.84	.76	.76	.78	.81	.79	.84	.84	.84
	Operating Ratio—Per cent Operating Expenses to Gross Operating Revenue	92.15	92.0	74.9	65.5	67.8	67.0	66.8	75.6	72.4	69.1
Virginian	Average Freight Train Load (Tons)	1712	1483	1508	1578	1469	1410	1111	1049	1132	809
	Average Rate Received per Freight Ton Mile (Cents)	.49	.42	.36	.34	.34	.34	.34	.35	.36	.4[illegible]
	Operating Ratio—Per cent Operating Expenses to Gross Operating Revenue	76.0	77.9	57.7	52.0	58.0	55.0	57.7	61.4	59.3	69.5

Certainly the comparison of the St. Paul and Virginian co-ordinated average freight train loadings, rates received per freight ton mile, and operating ratios does not justify any such editorial comment as given by you; and at any rate, you were not privileged to claim that I confined my comparison to one, rather than to a combination of the three essential factors.

Your editorial concludes with the following: "Neither side (referring to the advocates of electrification and steam operation) showed a real appreciation of the necessity of basing its argument on simple, sound economics," to which I must take decided exception, and beg to reiterate statements as set forth in my address as presented:

"What the stock owners and heads of railroads generally desire is to originate and move the greatest amount of business possible with the least cost to Capital and Operating Accounts."

"The locomotive problem must be attacked from a combined Transportation and Motive Power, and not from an Electrical or Mechanical Engineer's viewpoint. There are sufficient locomotives of all kinds now under construction and in service on American railroads to give correct data as to what can be accomplished under varying conditions by either the electric or steam method of developing tractive power, and if unwhitewashed reports of their performance can be obtained it will be of invaluable assistance to electrical and mechanical engineers generally in meeting the present and future motive power requirements."

"A steam locomotive in one section can be designed and placed under the control of one engineer and one fireman which will economically develop as much tractive power as may be necessary to haul the greatest amount of tonnage that can be concentrated in one train of suitable size for safe and quick handling over a division."

"The advantage of the electric locomotive for the handling of heavy tonnage would be from increasing the capacity of the line, and it might be that the greater business handled would justify the increased cost for installation and operation of electric locomotives as compared with steam locomotives."

"The New York *Tribune* has recently published a series of articles by Railroad Chairman and Presidents, on problems confronting the Carriers as regards adequate transportation facilities for the future, in which no reference was made to the necessity for any steam road electrification. Mr. Julius Kruttschnitt referred to the substitution of heavier modern for light obsolete locomotives, the elimination of every pound of unnecessary dead weight without sacrifice of strength or safety, and the conservation of fuel by the application of improvements and the education of employees. Mr. A. H. Smith referred to an electrification project for a city that would cost $60,000,000, but which would produce no revenue whatsoever. As Mr. Smith has had experience with electrification he ought to know. Mr. F. D. Underwood said that 'the average man does not realize what a wonderful machine the steam locomotive is'; 'that the capital expenditures involved in changing from steam to electric operation are enormous,' and that 'but for the notable improvements in steam locomotives which have enabled the roads to offset increased costs, they would have all been bankrupt."

"In line with the foregoing, Mr. J. J. Hill, a few years before his death stated that the Mallet type of steam locomotive had set back the time for electrification at least fifteen years, and Mr. L. F. Loree, who made the Mallet type of locomotive in the United States an established fact and who has done as much as, if not more than, any other railroad executive to increase locomotive and freight car capacities and efficiencies has as yet been unable to determine upon any steam road divisional electrification scheme in any part of the country that is justified as compared with steam operation."

"We all know that the foregoing named executives and railroads are representative of broad gauge policies and they do not hesitate to make improvements—when money can be procured—provided the expenditures will produce a proper rate of return in operating efficiency and economy in addition to the carrying charges."

"From 1903 to 1917 every mountain pass controlled by the Harriman lines—and two that were studied in reconnoissance—were investigated for electrification but in no case did the operating results justify the same as compared with steam operation."

"In the 1913 transactions of the American Institute of Electrical Engineers, pages 1845-1875, a paper on the subject of 'Mountain Railway Electrification,' by Mr. Allen H. Babcock, Electrical Engineer of the Southern Pacific, which related to the proposed electrification of a district of that line which included 38 miles of 2.4 per cent ruling grade between Bakersfield and Mojave, California, was published in full detail, and further the paper was placed in the hands of the engineers of two large electric locomotive manufacturers in this country with instructions to 'tear it to pieces.' With one exception, and which was a criticism directed to the point of view taken, rather than to the facts, by Mr. H. M. Hobart, of the General Electric Company (pages 1256-1260 in the transactions referred to) no criticism was made of Mr. Babcock's conclusion—which was that electrification was not justified."

"Similarly, in a report made in January, 1914, by Mr. J. P. Ripley, of the J. G. White Management Corporation, on the possibilities from the electrification of 23 miles of double track line of the Santa Fe between Trinidad, Colo., and Raton, New Mexico, covering ruling grades of from 3.32 to 3.5 percent and 10 degree curvature, over Raton Mountain summit, and at which time both the use of coke oven gas at 2 cents per 1,000 cubic feet delivered at the railway's power plant, and of purchased power were considered, electrification was not justified due to the relatively small average amount of traffic as compared with the tonnage to be moved at periods of great traffic density and on account of the savings in operation not even equalling the fixed charge brought about by electrification."

"In line with the foregoing, several years ago a report was made on the advisability of electrifying about 275 miles, or a division, of one of the more prominent western lines, and an erroneous comparison was made, first, between the existing antiquated and uneconomical steam and an up-to-date electric operation; and second, by omitting the investment required to bring the steam operation up to date. When all involved factors were properly adjusted the net capital expenditure of $4,000,000 required for electrification compared with $1,000,000 as needed for modernizing the steam equipment, and the estimated annual operating saving of approximately $750,000 from electrification was wiped out and replaced by a saving of $250,000 from a continuation of the improved steam operation."

"The foregoing are only a few cases where steam railway electrification projects that were thought to be entirely feasible, were, upon serious investigation, found not to be justified and indicate the caution that must be exercised in analyzing steam railroad motive power and transportation problems."

"To reflect initial and operating costs from a credit or an investment standpoint and to interpret faithfully on the basis of expert judgment backed by practical experience, the probable effect on the annual balance sheet, any investigation for the purpose of determining upon the advisability of electrical or

steam operation for an existing or new line of railroad should be made, preferably by a Committee consisting of experts in railway mechanical, electrical and civil engineering, transportation, and accounting, *without* an endeavor to modify the best steam railroading methods to suit the requirements of electric traction, and by keeping clearly in mind the fundamental fact that, while anything within reason is possible, provided enough money can be spent, if the Auditor's annual statement cannot show the balance on the right side of the ledger the project will have failed from the most important point of view."

"While there is much existing steam road trackage that can and should receive first consideration as regards electrification for the purpose of eliminating gases from underground terminals and tunnels, to give relief to terminal or line traffic congestion by combined rapidity and frequency of train movement in the vicinity of large commercial and industrial centers, or where transportation operations are auxiliary to mining or other industries requiring the extensive use of electricity, it would be financial suicide to electrify immediately adjacent connecting and intermediate long haul mileage, particularly in view of the improvements that can be made in both existing and new steam locomotives in the matter of reducing smoke, sparks, cinders and noise and in increasing general capacity, efficiency and economy in operation and maintenance."

"In view of past experience probably little if any financing of steam road electrification projects in the United States can be undertaken, particularly at present interest on money and labor and material prices, unless the returns are more adequately and fully guaranteed. In fact, few if any existing steam roads can justify or stand the additional capital investment required per mile of road for electrification, except for short distances under very special conditions such as prevailed on the Norfolk and Western, where the ventilation and 1.5 per cent grade line features of a five-eighths mile single track tunnel restricted the train movements to a 6 mile per hour basis on a congested traffic section of the main line, and even then only providing the fixed charges and operating expenses are not too excessive."

Apparently you did not hear or have before you the foregoing portion of my address when you prepared your editorial, and I am very glad to bring the same to your attention in order that you may know that there was a full appreciation of the necessity for basing the arguments in favor of steam operation on "simple, sound economics"—by referring to the facts as developed during the past fifteen years through the financial and operating results and the careful investigations as made by various representative railroads and high-class railroad executives.

In this connection wish to refer to the erroneous process followed in your abstracting of my address by merely referring to the omissions—which are bracketed—in the first paragraph of such abstract.

"Today, in consideration of the existing (traffic) rates and regulations as established by the Interstate Commerce Commission, (and the wages and working conditions as recommended by the Railroad Labor Board, it is assumed that the railroads as a whole will average net operating earnings equal to 6 per cent on their valuation as fixed from time to time by the Interstate Commerce Commission. Some railroads may earn more and some will earn less, but in the case of every line) the minimum fixed charge and the maximum operating and maintenance economy will be required if the stock owners are to receive even a reasonable return on their investment."

It is to be regretted that a representative paper associated with the technical press is not more careful in its reviews and abstracts of economic papers, in order that statements as set forth to the public interested will conform more nearly to the facts, and it is for this reason that I am bringing this particular case to your attention.

Yours very truly,

J. E. Muhlfeld.